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1801

ELEMENTS  
OF  
CHEMISTRY,

IN A  
NEW SYSTEMATIC ORDER,  
CONTAINING ALL THE  
MODERN DISCOVERIES.

ILLUSTRATED WITH THIRTEEN COPPERPLATES.

BY MR LAVOISIER,

Member of the Academies and Societies of Paris, London, Orleans,  
Bologna, Basil, Philadelphia, Haerlem, Manchester, &c. &c.

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TRANSLATED FROM THE FRENCH,  
BY ROBERT KERR, F. R. & A. SS. EDIN.  
Member of the Royal College of Surgeons, and of the Royal Physical  
Society of Edinburgh.

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FOURTH EDITION,  
WITH  
NOTES, TABLES, AND CONSIDERABLE ADDITIONS.

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# ADVERTISEMENT

OF THE

*TRANSLATOR.*

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THE very high character which Mr. Lavoisier has so deservedly acquired as a chemical philosopher, and the great revolution which he has effected in the theory of chemistry, had long made it much desired by all the cultivators of physical science, to have a connected account of his discoveries, and those of other chemical philosophers, on which his opinions are founded, together with an accurate exposition of the new theory, or rather of the regular concatenation of facts, which he has established, in consequence of these discoveries, made by himself and others. For the performance of this arduous undertaking, no one could possibly be better qualified than Mr. Lavoisier himself. He was not only thoroughly conversant in the discoveries of other philosophers, having, with infinite pains, repeated all their important experiments, and so varied most of them as to bring their results into a much

clearer view, but was himself the author of many important discoveries. The history, therefore, of these discoveries, and their proper arrangement, for conveying an exact idea of the new theory which he had deduced from them, could not, certainly, have been given to the world so well, or with so much propriety, by any other person.

This great desideratum in the history and science of chemistry, was accomplished in the year 1789, by the publication of the *Elements of Chemistry* by Mr. Lavoisier; and a copy of that excellent work having fallen accidentally into the hands of the translator, he was eager to give it to the public in English. He has received great satisfaction from the favourable reception which has been given to his first attempt to merit the favour of the public; and, whatever hesitation he may have originally felt, two former editions being completely exhausted, is a sufficient inducement for bringing forward a new one.

A new edition of the original having appeared at Paris in winter 1792-3, expectations were formed that the author might have made considerable improvements; but from a correspondence with Mr. Lavoisier, the translator is enabled to say, that the new edition, having been printed without his knowledge, is entirely a transcript from the former.

Some very material additions, though not numerous, have been made by the translator in this edition, relative to certain discoveries which have taken place in some parts of chemistry since the publication of the original; but as these are all distinctly marked in their proper places in the course of the work, it is not necessary to enumerate them here.

In the original, Mr. Lavoisier employs the scale of Reaumur's thermometer, for describing the degrees of temperature in his experiments: In the second and third edition of this translation, these are uniformly transferred into their correspondent degrees on the scale of Fahrenheit, which latter is universally used by the British philosophers. The weights employed by Mr. Lavoisier for detailing the ingredients and results of his various experiments, are, in the original, expressed in the customary aliquot parts of the Paris pound, *poids de marc*, which is divided very differently from the English pound, either troy or avoirdupois: To render these weights fully intelligible to the British reader, they are all, in this edition, reduced to decimal fractions of the pound, which will serve for all denominations.

In the course of the translation, several explanatory notes are added; principally for the purpose of rendering the doctrines of the author more

readily understood by beginners, and by those who have only been accustomed to the old language of chemistry : In consequence, however, of the perspicuity of the author, much fewer of these were found necessary than might have been expected from the comprehensive nature of the work. It was intended by the author to convey a general view of the new chemical theory, rather than to give a system of chemistry ; yet such is the excellence of its plan and execution, that, with these limited intentions, it is the best body of chemical philosophy extant.

In a small number of places, the translator has taken the liberty of throwing to the bottom of the page, in notes, some parenthetical expressions, not directly connected with the subject, which, in their original place, rather tended to confuse the sense : These, and the original notes of the author, are distinguished by the letter A ; and to those which the translator has ventured to add, the letter T is subjoined. Some discoveries, which have been made in various parts of chemistry since the publication of the original, are added in this translation in their proper places.

Mr. Lavoisier has given, in an appendix, several very useful tables, for facilitating the calculations now necessary in the advanced state of modern chemistry, wherein the most scrupulous accuracy



is required: These are now as indispensibly requisite to the operations of the chemical philosopher, as the Ephemerides, and Nautical Almanacs, and Logarithmic Tables, are to the Navigator, Astronomer, and Geometrician. These tables are all retained in this translation; being, however, reduced to the standards of British weights and measures, with proper rules for making the necessary conversions from the weights and measures of France: And the translator is proud to acknowledge his obligations to the learned Professor of Natural Philosophy in the University of Edinburgh, and to his friend Dr. Rotheram\*, who kindly supplied him with the necessary information, and took the trouble of making a number of very laborious calculations, for this purpose. With the same assistance, several very useful additional tables have been given in the Appendix, which need not be here enumerated, as they will distinctly appear in their proper places.

*POSTSCRIPT to the Third Edition.*

THE Philosophical world has now infinitely to deplore the tragical and untimely death of the great LAVOISIER; who has left a rare example of

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*X Dr. Rotheram. Formerly Professor of Chemistry in the University of Edinburgh, and now Professor of Natural Philosophy in the University of St. Andrew's.*

splendid talents and great wealth, at the same time immerfed in numerous and important public employments, which he executed with diligent intelligence, and devoting his princely fortune and vast abilities to the sedulous cultivation and most successful improvement of the Sciences. If the sanguinary tyranny of the monster Robespierre had committed only that outrage against eternal Justice, a succeeding age of the most perfect government would scarcely have sufficed, to France and to the world, to repair the prodigious injury that loss has produced to chemistry, and to all the sciences and economical arts with which it is connected.

Had Lavoisier lived, as expressed in a letter received from him by the Translator a short while before his massacre, it was his intention to have republished these Elements in an entirely new form, composing a complete System of Philosophical Chemistry: And, as a mark of his satisfaction with the fidelity of this translation, he proposed to have conveyed to the Translator, sheet by sheet as it should come from the press, that new and invaluable work, alas! now for ever lost.

*This Edition has been revised and corrected by the Translator, and is published by order of the General Committee of the National Institute of France.*

# P R E F A C E

OF THE

*AUTHOR.*

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WHEN I began the following Work, my only object was to extend and explain more fully the Memoir which I read at the public meeting of the Academy of Sciences in the month of April 1787, on the necessity of reforming and completing the Nomenclature of Chemistry. While engaged in this employment, I perceived, better than I had ever done before, the justice of the following maxims of the Abbé de Condillac, in his system of Logic, and some other of his works.

“ We think only through the medium of  
“ words.—Languages are true analytical methods.  
“ —Algebra, which is adapted to its purpose in  
“ every species of expression, in the most simple,  
“ most exact, and best manner possible, is at the  
“ same time a language and an analytical method.  
“ —The art of reasoning is nothing more than  
“ a language well arranged.”

Thus, while I thought myself employed only in forming a Nomenclature, and while I proposed to myself nothing more than to improve the chemical language, my work transformed itself by degrees, without my being able to prevent it, into a treatise upon the Elements of Chemistry.

The impossibility of separating the Nomenclature of a science from the science itself, is owing to this, that every branch of physical science must consist of three things; the series of facts which are the objects of the science; the ideas which represent these facts; and the words by which these ideas are expressed. Like three impressions of the same seal, the word ought to produce the idea, and the idea to be a picture of the fact. And as ideas are preserved and communicated by means of words, it necessarily follows, that we cannot improve the language of any science, without at the same time improving the science itself; neither can we, on the other hand, improve a science, without improving the language or nomenclature which belongs to it. However certain the facts of any science may be, and however just the ideas we may have formed of these facts, we can only communicate false or imperfect impressions of these ideas to others, while we want words by which they may be properly expressed.

To those who will consider it with attention, the first part of this treatise will afford frequent proofs of the truth of these observations. But as, in the conduct of my work, I have been obliged to observe an order of arrangement essentially differing from what has been adopted in any other chemical work yet published, it is proper that I should explain the motives which have led me to adopt that arrangement.

It is a maxim universally admitted in Geometry, and indeed in every branch of knowledge, that, in the progress of investigation, we should proceed from known facts to what is unknown. In early infancy, our ideas spring from our wants, the sensation of want exciting the idea of the object by which it is to be gratified. In this manner, from a series of sensations, observations, and analyses, a successive train of ideas arises, so linked together, that an attentive observer may trace back, to a certain point, the order and connection of the whole sum of human knowledge.

When we begin the study of any science, we are in a situation, respecting that science, similar to children; and the course by which we have to advance, is precisely the same which Nature follows in the formation of their ideas. In a child, the idea is merely an effect produced by a sensation;

and, in the same manner, in commencing the study of a physical science, we ought to form no idea but what is a necessary consequence, and immediate effect, of an experiment or observation. Besides, he who enters upon the career of science, is in a less advantageous situation than a child who is acquiring his first ideas. To the child, Nature gives various means of rectifying any mistakes he may commit respecting the salutary or hurtful qualities of the objects which surround him. On every occasion his judgments are corrected by experience; want and pain are the necessary consequences arising from false judgment; gratification and pleasure are produced by judging aright. Under such masters, we cannot fail to become well informed; and we soon learn to reason justly, when want and pain are the necessary consequences of a contrary conduct.

In the study and practice of the sciences it is entirely different; the false judgments we may form neither affect our existence nor our welfare; and we are not compelled by any physical necessity to correct them. Imagination, on the contrary, which is ever wandering beyond the bounds of truth, joined to self-love and that self-confidence we are so apt to indulge, prompt us to draw conclusions which are not immediately derived from facts; so that we become in some measure interested in deceiving ourselves. Hence it is by



no means surprising, that, in the science of physics in general, men have so often formed suppositions, instead of drawing conclusions. These suppositions, handed down from one age to another, acquire additional weight from the authorities by which they are supported, till at last they are received, even by men of genius, as fundamental truths.

The only method of preventing such errors from taking place, and of correcting them when formed, is to restrain and simplify our reasoning as much as possible. This depends entirely on ourselves, and the neglect of it is the only source of our mistakes. We must trust to nothing but facts: These are presented to us by Nature, and cannot deceive. We ought, in every instance, to submit our reasoning to the test of experiment, and never to search for truth, but by the natural road of experiment and observation. Thus mathematicians obtain the solution of a problem, by the mere arrangement of data, and by reducing their reasoning to such simple steps, and to conclusions so very obvious, as never to lose sight of the evidence which guides them.

Thoroughly convinced of these truths, I have imposed upon myself, as a law, never to advance but from what is known to what is unknown; never to form any conclusion which is not an

immediate consequence necessarily flowing from observation and experiment ; and always to arrange the facts, and the conclusions which are drawn from them, in such an order as shall render it most easy for beginners in the study of chemistry thoroughly to understand them. Hence I have been obliged to depart from the order usually observed in courses of lectures and treatises upon chemistry ; which always assume the first principles of the science as known, whereas the pupil or the reader should never be supposed to know them till they have been explained in subsequent lessons. In almost every instance, chemical authors and lecturers begin by treating of the elements of matter, and by explaining the table of affinities ; without considering that, in so doing, they must bring the principal phenomena of chemistry into view at the very outset : They make use of terms which have not been defined, and suppose the science to be understood by the very persons they are only beginning to teach.

It ought likewise to be considered, that very little of chemistry can be learned in a first course, which is hardly sufficient to make the language of the science familiar to the ears, or the apparatus familiar to the eyes. It is almost impossible to become a chemist in less than three or four years of constant application.



These inconveniences are occasioned, not so much by the nature of the subject, as by the method of teaching it; and, to avoid them, I was chiefly induced to adopt a new arrangement of chemistry, which appeared to be more consonant to the order of Nature. I acknowledge, however, that in thus endeavouring to avoid difficulties of one kind, I have found myself involved in others of a different species, some of which I have not been able to remove; but I am persuaded, that such as remain do not arise from the nature of the order I have adopted, but are rather consequences of the imperfection under which chemistry still labours. This science has many chasms, which interrupt the series of facts, and often render it extremely difficult to reconcile these with each other. It has not, like the elements of geometry, the advantage of being a complete science, the parts of which are all closely connected together. Its actual progress, however, is so rapid, and the facts, under the modern doctrine, have assumed so happy an arrangement, that we have ground to hope, even in our own times, to see it approach near to the highest state of perfection of which it is susceptible.

The rigorous law from which I have never deviated, of forming no conclusions which are not fully warranted by experiment, and of never supplying the absence of facts, has prevented me

from comprehending in this work the branch of chemistry which treats of affinities, although it is perhaps the best calculated of any part of chemistry for being reduced into a completely systematic body. Messrs. Geoffroy, Gellert, Bergman, Scheele, De Morveau, Kirwan, and many others, have collected a great number of particular facts upon this subject, which only wait for a proper arrangement. But the principal data are still wanting, or, at least, those we have are either not sufficiently defined, or not sufficiently proved, to become the foundation for so very important a branch of chemistry. This science of affinities, or elective attractions, holds the same place with regard to the other branches of chemistry, that the higher or transcendental geometry does with respect to the simpler and elementary part. And I thought it improper to involve those simple and plain elements, which I flatter myself the greatest part of my readers will easily understand, in the obscurities and difficulties which still attend that other very useful and necessary branch of chemical science.

Perhaps a sentiment of self-love may, without my perceiving it, have given additional force to these reflections. Mr. de Morveau is at present engaged in publishing the article *Affinity* in the Methodical Encyclopædia: and I had more reasons than one to decline entering upon a work in which he is employed.

It will, no doubt, be a matter of surprise, that in a treatise upon the elements of chemistry, there should be no chapter on the constituent and elementary parts of matter; but I may here observe, that the fondness for reducing all the bodies in nature to three or four elements, proceeds from a prejudice which has descended to us from the Greek Philosophers. The notion of four elements, which, by the variety of their proportions, compose all the known substances in nature, is a mere hypothesis, assumed long before the first principles of experimental philosophy or of chemistry had any existence. In those days, without possessing facts, they framed systems; while we, who have collected facts, seem determined to reject even these, when they do not agree with our prejudices. The authority of those fathers of human philosophy still carry great weight: and there is reason to fear that it will bear hard even upon generations yet to come.

It is very remarkable, notwithstanding the number of philosophical chemists who have supported the doctrine of the four elements, that there is not one who has not been led, by the evidence of facts, to admit a greater number of elements into their theory. The first chemical authors, after the revival of letters, considered sulphur and salt as elementary substances, entering into the composition of a great number of bodies.

Hence, instead of four, they admitted the existence of six elements. Beccher assumed the existence of three kinds of earth; from the combination of which, in different proportions, he supposed all the varieties of metallic substances to be produced. Stahl gave a new modification to this system: And succeeding chemists have taken the liberty to make or to imagine changes and additions of a similar nature. All these chemists were carried along by the genius of the age in which they lived, being satisfied with assertions instead of proofs; or, at least, often admitting as proofs the slightest degrees of probability, unsupported by that strictly rigorous analysis which is required by modern philosophy.

All that can be said upon the number and nature of elements, is, in my opinion, confined to discussions entirely of a metaphysical nature. The subject only furnishes us with indefinite problems, which may be solved in a thousand different ways, not one of which, in all probability, is consistent with nature. I shall, therefore, only add upon this subject, that if, by the term *elements*, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them; but if we apply the term *elements* or *principles of bodies*, to express our idea of the last point which analysis is capable of reaching, we must admit, as elements

all the substances into which we are able to reduce bodies by decomposition. Not that we are intitled to affirm, that these substances which we consider as simple, may not themselves be compounded of two, or even of a greater number of more simple principles. But since these principles cannot be separated, or rather since we have not hitherto discovered the means of separating them, they act with regard to us as simple substances, and we ought never to suppose them compounded until experiment and observation have proved them to be so.

The foregoing reflections upon the progress of chemical ideas naturally apply to the words by which these ideas are expressed. Guided by the work which, in the year 1787, Messrs de Morveau, Berthollet, de Fourcroy, and I composed upon the Nomenclature of Chemistry, I have endeavoured, as much as possible, to denominate simple bodies by simple terms: and I was naturally led to name these first. It will be recollected, that we were obliged to retain that name of any substance by which it had been long known in the world, and that in two cases only we took the liberty of making alterations; first, in the case of those which were but newly discovered, and had not yet obtained names, or at least which had been known but for a short time, and the names of which had not yet received the sanction of the public; and



secondly, when the names which had been adopted, whether by the ancients or the moderns, appeared to us to express evidently false ideas ; when they confounded the substances, to which they were applied, with others possessed of different, or perhaps opposite qualities. We made no scruple, in this case, of substituting other names in their room : and the greater number of these were borrowed from the Greek language. We endeavoured to frame them in such a manner as to express the most general and the most characteristic quality of the substances : and this was attended with the additional advantage both of assisting the memory of beginners, who find it difficult to remember a new word which has no meaning, and of accustoming them early to admit no word without connecting with it some determinate idea.

To those bodies which are formed by the union of several simple substances, we gave new names compounded in such a manner as the nature of the substances directed. But, as the number of known double combinations is already very considerable, the only method by which we could avoid confusion, was to divide these into classes. In the natural order of ideas, the name of the class or genus is that which expresses a quality common to a great number of individuals : the name of the species, on the contrary,

expresses a quality peculiar to certain individuals only.

These distinctions are not, as some may imagine, merely metaphysical, but are established by Nature. "A child," says the Abbé de Condillac, "is taught to give the name *tree* to the first which "is pointed out to him. The next tree he "sees presents the same idea; and he gives it the "same name. This he does likewise to a third "and a fourth; till at last the word *tree*, which "he at first applied to an individual, comes to "be employed by him as the name of a class or "a genus; it becomes an abstract idea, which "comprehends all trees in general. But when he "learns that all trees do not serve the same "purpose, that they do not all produce the same "kind of fruit, he soon distinguishes them by "specific and particular names." This is the logic of all the sciences, and is very naturally applicable to chemistry.

The acids, for example, are compounded of two substances, which we consider as simple. The one constitutes acidity, and is common to all acids: and, from this substance, the name of the class or the genus ought to be taken. The other is peculiar to each acid, and distinguishes it from the rest: and from this substance is to be taken the name of the species. But, in the greater

number of acids, these two constituent elements, the acidifying principle, and that which it acidifies, may exist in different proportions, constituting all the possible points of equilibrium or of saturation. This is the case in the sulphuric and the sulphurous acids : and these two states of the same acid we have marked by varying the termination of the specific name.

Metallic substances which have been exposed to the joint action of the air and of fire, lose their metallic lustre, increase in weight, and assume an earthy appearance. In this state, like the acids, they are compounded of a principle which is common to all, and of one which is peculiar to each. In the same way, therefore, we have thought proper to class them under a generic name, derived from the common principle ; for which purpose, we have adopted the term *oxyd* ; and we distinguish them from each other by the particular name of the metal to which each belongs.

Combustible substances, which, in acids and metallic oxyds, are specific and particular principles, are capable of becoming, in their turn, common principles of a great number of compounds. The sulphurous combinations have been long the only known ones in this kind. Now, however, we know, from the experiments of Messrs Vandermonde, Monge, and Berthollet,



that carbon may be combined with iron, and perhaps with several other metals; and that from this combination, according to the proportions, may be produced steel, plumbago, &c. We know likewise, from the experiments of M. Pelletier, that phosphorus may be combined with a great number of metallic substances. These different combinations we have classed under generic names taken from the common substance, with a termination which marks this analogy, specifying them by another name taken from that substance which is proper to each.

The nomenclature of bodies compounded of three simple substances was attended with still greater difficulty; not only on account of their number, but particularly, because we cannot express the nature of their constituent principles without employing more compound names. In the bodies which form this class, such as the neutral salts, for instance, we had to consider, 1st, The acidifying principle, which is common to them all; 2d, The acidifiable principle which constitutes their peculiar acid; 3d, The saline, earthy, or metallic basis, which determines the particular species of salt. Here we derived the name of each class of salts from the name of the acidifiable principle common to all the individuals of that class; and distinguished each species, by the name of its peculiar saline, earthy, or metallic basis.

A salt, though compounded of the same three principles, may, nevertheless, by the mere difference of their proportion, be in three different states of saturation. The nomenclature we have adopted would have been defective, had it not expressed these different states: and this we attained chiefly by changes of termination uniformly applied to the same state of the different salts.

In short, we have advanced so far, that from the name alone may be instantly found what the combustible substance is which enters into any combination; whether that combustible substance be combined with the acidifying principle, and in what proportion; what is the state of the acid; with what basis it is united; whether the saturation be exact, or whether the acid or the basis be in excess.

It may easily be supposed, that it was not possible to attain all these different objects without departing, in some instances, from established custom, and adopting terms which, at first sight, may appear uncouth and barbarous. But we considered that the ear is soon habituated to new words, especially when they are connected with a general and rational system. The names, besides, which were formerly employed, such as *powder of algaroth*, *salt of alembroth*, *pompholix*, *phagadenic water*, *turbith mineral*, *colcothar*, and

many others, were neither less barbarous nor less uncommon. It required a great deal of practice, and no small degree of memory, to recollect the substances to which they were applied; much more to recollect the genus of combination to which they belonged. The names of *oil of tartar per deliquium*, *oil of vitriol*, *butter of arsenic and of antimony*, *flowers of zinc*, &c. were still more improper, because they suggested false ideas; for, in the whole mineral kingdom, and particularly in the metallic class, there exists no such thing as butters, oils, or flowers. In short, the substances to which these fallacious names were given, are rank poisons.

When we published our essay on the Nomenclature of Chemistry, we were reproached for having changed the language which was spoken by our masters, which they stamped with their authority, and have handed down to us. But those who reproach us on this account, have forgotten that Bergman and Macquer urged us to make this reformation: In a letter which the learned Professor of Upsal, M. Bergman, wrote, a short time before he died, to Mr Morveau, he bids him *spare no improper names; those who are learned, will always be learned; and those who are ignorant will thus learn sooner.*

There is an objection to this work, which is perhaps better founded; that I have given no account of the opinions of those who have gone before me, and have only stated my own without examining those of others. By this I have been prevented from doing that justice to my associates, and more especially to foreign chemists, which I wished to render them. But I beseech the reader to consider, that, if I had filled an elementary work with a multitude of quotations, if I had allowed myself to enter into long dissertations on the history of the science, and the works of those who have studied it, I must have lost sight of the true object I had in view, and should have produced a work extremely tiresome to beginners.

It is not the history of the science, or of the human mind, that we are to attempt in an elementary treatise. Our only aim should be ease and perspicuity; and with the utmost care to keep every thing out of view which may draw aside the attention of the student. It is a road which we should be continually rendering more smooth, and from which we must endeavour to remove every obstacle which can occasion delay. The sciences, from their own nature, present a sufficient number of difficulties, though we add not those which are foreign. But, besides this, chemists will easily perceive, that, in the first part of my work, I make very little use of any experiments but those

which were made by myself. If at any time I have adopted, without acknowledgement, the experiments or the opinions of M. Berthollet, M. Fourcroy, M. de la Place, M. Monge, or, in general, of any of those whose principles are the same with my own, it is owing to this circumstance, that frequent intercourse, and the habit of communicating our ideas, our observations, and our ways of thinking, to each other, have established between us a sort of community of opinions, in which it is often difficult for every one to know his own.

These remarks on the order which I thought myself obliged to follow in the arrangement of proofs and ideas, are to be applied only to the first part of this work. It is the only one which contains the general sum of the doctrine I have adopted, and to which I wished to give a form completely elementary.

The second part is composed chiefly of tables of the nomenclature of the neutral salts. To these I have only added general explanations, the object of which is to point out the most simple processes for obtaining the different kinds of known acids. This part contains nothing which I can call my own; and presents only a very short abridgement of the results of these processes, extracted from the works of different authors.



In the third part, I have given a description, in detail, of all the operations connected with modern chemistry. I have long thought that a work of this kind was much wanted: and I am convinced it will not be without its use. The method of performing experiments, and particularly those of modern chemistry, is not so generally known as it ought to be: and had I, in the different memoirs which I have presented to the Academy, been more particular in the detail of the manipulations of my experiments, it is probable I should have made myself better understood, and the science might have made a more rapid progress. The order for the different matters contained in this third part appears to me almost arbitrary: and the only one I have observed, is to class together, in each of the chapters of which it is composed, those operations which are most connected with one another. I need hardly mention, that this part could not be borrowed from any other work, and that, in the principal articles it contains, I could not derive assistance from any thing but the experiments which I have made myself.

I shall conclude this preface by transcribing, literally, some observations of the Abbé de Condillac, which I think describe, with a good deal of truth, the state of Chemistry at a period not far distant from our own. These observations

were made on a different subject; but they will not on this account, have less force, if the application of them be just.

‘ Instead of applying observation to the things  
‘ we wished to know, we have chosen rather to  
‘ imagine them. Advancing from one ill-founded  
‘ supposition to another, we have at last bewildered  
‘ ourselves amid a multitude of errors. These  
‘ errors, becoming prejudices, are, of course,  
‘ adopted as principles, and we thus bewilder  
‘ ourselves more and more. The method, too,  
‘ by which we conduct our reasonings is absurd.  
‘ We abuse words which we do not understand,  
‘ and call this the art of reasoning. When matters  
‘ have been brought this length, when errors  
‘ have been thus accumulated, there is but one  
‘ remedy, by which order can be restored to the  
‘ faculty of thinking; this is, to forget all that  
‘ we have learned, to trace back our ideas to  
‘ their source, to follow the train in which they  
‘ rise, and, as Lord Bacon says, to frame the  
‘ human understanding anew.

‘ This remedy becomes the more difficult, in  
‘ proportion as we think ourselves the more  
‘ learned. Might it not be thought, that works  
‘ which treat of the sciences with the utmost  
‘ perspicuity, and with the greatest order and  
‘ precision, must be understood by every body?

‘ The fact is, those who have never studied any  
‘ thing will understand them better than those who  
‘ have studied a great deal, and especially than  
‘ those who have written a great deal.’

In another place, the Abbé de Condillac adds :  
‘ But, notwithstanding, the sciences have improved,  
‘ because philosophers have applied themselves  
‘ with more attention than formerly to observe  
‘ nature, and have communicated to their language  
‘ that precision and accuracy which they have  
‘ employed in their observations.—By correcting  
‘ their language, they have reasoned better.’



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# E L E M E N T S

OF

# C H E M I S T R Y

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## P A R T I.

Of the Formation and Decomposition of Aëri-  
form Fluids—of the Combustion of Simple  
Bodies—and of the Formation of Acids.

## C H A P. I.

*Of the Combination of Caloric, and the Formation  
of Elastic Aëriform Fluids.*

**T**HAT every body, whether solid or fluid,  
is augmented in all its dimensions by any  
increase of its sensible heat, was long ago fully  
established as a physical axiom, or universal pro-  
position, by the celebrated Boerhaave. Such  
facts as have been adduced, for controverting the

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generality of this principle, offer only fallacious results, or, at least, such as are so complicated with foreign circumstances, as to mislead the judgment. But, when we separately consider the effects, so as to deduce each from the cause to which they separately belong, it is easy to perceive, that the separation of particles by heat is a constant and general law of nature.

When we have heated a solid body to a certain degree, and have thereby caused its particles to separate from each other, if we allow the body to cool, its particles again approach each other in the same proportion in which they were separated by the increased temperature; the body returns by the same degrees of expansion through which it before extended; and, if brought back to the same temperature which it possessed at the commencement of the experiment, it recovers exactly the same dimensions which it formerly occupied. We are still very far from being able to produce the degree of absolute cold, or total deprivation of heat, being unacquainted with any degree of coldness which we cannot suppose capable of still farther augmentation. Hence it follows, that we are incapable of causing the ultimate particles of bodies to approach each other as near as possible, and that these particles of bodies do not touch each other in any state hitherto known. Though

this be a very singular conclusion it is impossible to be denied.

It may be supposed, that, since the particles of bodies are thus continually impelled by heat to separate from each other, they would have no connection between themselves; and that, of consequence, there could be no solidity in nature, unless these particles were held together by some other power which tended to unite them, and, so to speak, to chain them together: This power, whatever be its cause, or manner of operation, is named Attraction.

Thus the particles of all bodies may be considered as subject to the action of two opposite powers, Repulsion and Attraction, between which they remain in equilibrio. So long as the attractive force remains stronger, the body must continue in a state of solidity: but if, on the contrary, heat has so far removed these particles from each other, as to place them beyond the sphere of attraction, they lose the cohesion they before had with each other, and the body ceases to be solid.

Water gives us a regular and constant examples of these facts. Whilst below  $32^{\circ}$  of Fahrenheit's scale\*, it remains solid, and is called ice.

\* Whenever the degree of heat occurs in the original, it is stated by the author according to Reaumur's thermo-

Above that degree of temperature, its particles being no longer held together by reciprocal attraction, it becomes liquid; and, when we raise its temperature above  $212^{\circ}$ , its particles, giving way to the repulsion caused by the heat, assume the state of vapour or gas, and the water is changed into an æriform fluid.

The same may be affirmed of all bodies in nature. They are either solid, or liquid, or in the state of elastic æriform vapour, according to the proportion which takes place between the attractive force inherent in their particles, and the repulsive power of the heat acting upon these; or, what amounts to the same thing, in proportion to the degrees of heat to which they are exposed.

It is difficult to comprehend these phenomena, without admitting them as the effects of a real and material substance, or very subtle fluid, which, insinuating itself between the particles of bodies, separates them from each other. Even allowing that the existence of this fluid may be hypothetical, we shall see in the sequel, that it explains the phenomena of nature in a very satisfactory manner.

This substance, whatever it is, being the cause

meter; but the translator has thought it more convenient to use Fahrenheit's scale, as more generally employed and understood in Britain.—T.

of heat, or, in other words, the sensation which we call *warmth*, being caused by the accumulation of this substance, we cannot, in strict language, distinguish it by the term *heat*, because the same name would then very improperly express both cause and effect. For this reason, in the memoir which I published in 1777\*, I gave it the names of *igneous fluid* and *matter of fluid*: And, since that time, in the work † published by Mr de Morveau, Mr Berthollet, Mr de Fourcroy, and myself, upon the reformation of chemical nomenclature, we thought it necessary to reject all periphrastic expressions, which both lengthen physical language, and render it less distinct, and which even frequently do not convey sufficiently just ideas of the object intended. Wherefore, we have distinguished the cause of heat, or that exquisitely elastic fluid which produces it, by the term of *caloric*. Besides, that this expression fulfils our object in the system which we have adopted, it possesses this farther advantage, that it accords with every species of opinion; since, strictly speaking, we are not obliged to suppose this to be a real substance, it being sufficient, as will more clearly appear in the sequel of this work, that it be considered as the

\* Collections of the French Academy of Sciences for that year, p. 420.

† New Chemical Nomenclature.

repulsive cause, whatever that may be, which separates the particles of matter from each other ; so that we are still at liberty to investigate its effects in an abstract and mathematical manner.

In the present state of our knowledge, we are unable to determine whether light be a modification of caloric, or caloric be, on the contrary, a modification of light. This, however, is indisputable, that, in a system where only decided facts are admissible, and where we avoid, as far as possible, to suppose any thing to be, that is not really known to exist, we ought provisionally to distinguish, by distinct terms, such things as are known to produce different effects. We therefore distinguish light from caloric ; though we do not therefore deny that these have certain qualities in common, and that, in certain circumstances, they combine with other bodies almost in the same manner, and produce, in part, the same effects.

What I have already said, may suffice to determine the idea affixed to the word *caloric* ; but there remains a more difficult attempt, which is, to give a just conception of the manner in which caloric acts upon other bodies. Since this subtile matter penetrates through the pores of all known substances—since there are no vessels through which it cannot escape—and, consequently, as there are none which are capable of retaining it—we can only come at the



knowledge of its properties by effects which are fleeting and difficultly ascertainable. It is in those things which we neither see nor feel, that it is especially necessary to guard against the extravagancy of our imagination, which for ever inclines to step beyond the bounds of truth, and is very difficultly restrained within the narrow limits of facts.

We have already seen, that the same body becomes solid, or fluid, or æriform, according to the quantity of caloric by which it is penetrated; or, more strictly, according as the repulsive force exerted by the caloric is equal to, stronger, or weaker than, the attraction of the particles of the body it acts upon.

But, if these two powers only existed, bodies would become liquid at an indivisible degree of the thermometer, and would almost instantaneously pass from the solid state of aggregation to that of æriform elasticity. Thus water, for instance, at the very instant when it ceases to be ice, would begin to boil, and would be transformed into an æriform fluid, having its particles scattered indefinitely through the surrounding space. That this does not happen, must depend upon the action of some third power. The pressure of the atmosphere prevents this separation; and causes the water to remain in the liquid state, until raised to the temperature indicated by  $212^{\circ}$  on the scale of Fahrenheit's thermo-

meter: the quantity of caloric which it receives in the lower temperatures being insufficient to overcome the pressure of the atmosphere.

Whence it appears, that, without this atmospheric pressure, we should not have any permanent liquid, and should only see bodies in that state of existence in the very instant of melting; for the smallest additional caloric would then instantly separate their particles, and dissipate them through the surrounding medium. Besides, without this atmospheric pressure, we should not even have any proper aëriform fluids; because the moment the force of attraction is overcome by the repulsive power of the caloric, the particles of bodies would separate themselves indefinitely, having nothing to give limits to their expansion, unless their own gravity might collect them together, so as to form an atmosphere.

Simple reflection, upon the most common experiments, is sufficient to evince the truth of these positions. They are more particularly proved by the following experiment, which I published in the *Memoirs of the French Academy of Sciences*, for 1777, p. 426.

Having filled with Sulphuric Ether \* a small

\* I shall afterwards give a definition, and explain the properties of the liquor called *Ether*; I shall therefore

narrow glass vessel, A, (Plate VII. Fig. 17.), standing upon its stalk P; the vessel, which is from twelve to fifteen lines diameter, is covered by a wet bladder, tied round its neck with several turns of strong thread; for greater security, a second bladder is fixed over the first. The vessel should be filled in such a manner with the ether, as not to leave the smallest portion of air between the liquor and the bladder. It is now placed under the recipient BCD of an air-pump, of which the upper part B is fitted with a leather collar, through which passes a wire EF, having its point F very sharp; and in the same receiver there is placed the barometer GH. The whole being thus disposed, let the recipient be exhausted, and then, by pushing down the wire EF, a hole is made in the bladder. Immediately the ether begins to boil with great violence, and is changed into an elastic æriform fluid, which fills the receiver. If the quantity of ether be sufficient to leave a few drops in the phial, after the evaporation is finished, the elastic fluid produced will sustain the mercury in the barometer attached to the air-pump, at eight or ten inches in winter, and from twenty to

only premise here that it is a very volatile, and highly inflammable liquor, having a considerably smaller specific gravity than water, or even spirit of wine.—A.

H

twenty-five in summer\*. To render this experiment more complete, we may introduce a small thermometer into the phial A, containing the ether which will be found to descend considerably during the evaporation.

The only effect produced in this experiment, is, the taking away the weight of the atmosphere, which, in its ordinary state, presses on the surface of the ether; and the effects resulting from this removal, evidently prove, that, in the ordinary temperature of the earth, ether would always exist in an aëriform state, but for the pressure of the atmosphere, and that the change of the ether from the liquid to the aëriform state is accompanied by a considerable diminution of temperature; because, during the evaporation, a part of the caloric, which was before in a free state, or at least in equilibrium† in the surrounding bodies, combines with the ether, and causes it to assume the aëriform state.

The same experiment succeeds with all eva-

\* It would have been more satisfactory if the Author had specified the degrees of the thermometer at which these heights of the mercury in the barometer are produced.—T.

† I should rather suppose, according to Mr Lavoisier's own principles, that the evaporation is produced in consequence of the equilibrium between the repulsive force of the caloric contained in the ether, and the resistance to expansion exerted by the atmospheric pressure being removed.—T.

porable fluids, such as alkohol, water, and even mercury; with this difference, that the atmosphere, formed in the receiver by alkohol only, supports the attached barometer about one inch in winter, and about four or five inches in summer; that formed by water, in the same situation, raises the mercury only a few lines; and that produced by quicksilver raises it but a few fractions of a line. There is, therefore, less fluid evaporated from alkohol than from ether; less from water than from alkohol; and still less from mercury than from either; consequently, there is less caloric employed, and less cold produced, which quadrates exactly with the results of these experiments.

Another species of experiment proves very evidently, that the aëriform state is a modification of bodies dependent on the degree of temperature, and on the pressure which these bodies undergo. In a Memoir read by Mr de la Place and myself to the Academy in 1777, which has not been printed, we have shewn, that, when ether is subjected to a pressure equal to twenty-eight inches of the barometer, or about the medium pressure of the atmosphere, it boils at the temperature of about  $104^{\circ}$ , or  $10.25^{\circ}$  of the thermometer. Mr de Luc, who has made similar experiments with spirit of wine, finds it to boil at  $182.75^{\circ}$ ; And all the world knows, that water boils at  $212^{\circ}$ . Now, boiling being only the evaporation of a

liquid, or the moment of its passing from the fluid to the aëriform state, it is evident, that, if we keep ether continually at or above the temperature of  $106.25^{\circ}$ , and under the common pressure of the atmosphere, we shall have it always in an elastic aëriform state; and that the same thing will happen with alkohol when above  $182.75^{\circ}$ , and with water when above  $212^{\circ}$ ; all which are perfectly conformable to the following experiment\*.

I filled a large vessel ABCD (Plate VII. Fig. 15.) with water, at  $110.75^{\circ}$ , or  $113^{\circ}$ ; I suppose the vessel transparent, that we may see what takes place in the experiment; and we can easily hold the hands in water at that temperature without inconvenience. Into this vessel I plunged some narrow-necked bottles F, G, filled with the water, and turned up, so as to rest on their mouths on the bottom of the vessel. Having next put some ether into a very small matrafs, with its neck, *abc*, twice bent as in the plate, I plunged this matrafs into the water, having its neck inserted into the mouth of one of the bottles F. Immediately on feeling the effects of the heat, communicated to it by the water in the vessel ABCD, the ether began to boil, and the caloric, entering into combination with it, changed it in-

\* Vide Memoirs of the French Academy, anno 1780, p. 335.—A.



to an elastic æriform fluid, with which I filled several bottles successively, F, G, &c.

This is not the place to enter upon the examination of the nature and properties of this æriform fluid, which is extremely inflammable. But, confining myself to the object at present in view, without anticipating circumstances, which I am not to suppose the reader to know, I shall only observe, that the ether, from this experiment, is almost only capable of existing in the æriform state in our usual temperatures; for, if the weight of our atmosphere was only equal to between 20 and 24 inches of the barometer, instead of 28 inches, we should never be able to obtain ether in the liquid state, at least in summer. The preparation of ether would consequently be impossible upon mountains of a moderate degree of elevation, as it would be converted into gas immediately upon being produced, unless we employed recipients of extraordinary strength, assisted by refrigeration and compression. And, lastly, the temperature of the blood being nearly that at which ether passes from the liquid to the æriform state, it must evaporate in the *primæ viæ*; and consequently it is very probable that the medical properties of this fluid depend chiefly upon its mechanical effect.

These experiments succeed better with nitrous ether, because it evaporates in a lower temperature than sulphuric ether. It is more difficult

to obtain alkohol in the aëriform state : because, as it requires a temperature of  $182.75^{\circ}$  to raise it to vapour, the water of the bath must be almost boiling ; and it is impossible to plunge the hands into it at that temperature.

It is evident, that, if water were used in the foregoing experiment, it would be changed into gas, when exposed to a temperature superior to that at which it boils. Although thoroughly convinced of this, Mr de la Place and myself judged it necessary to confirm it by the following direct experiment. We filled a glass-jar, A, (Plate VII. Fig. 5.) with mercury, and placed it, with its mouth downwards, in a dish, B, likewise filled with mercury ; and introduced about two drams of water into the jar, which rose to the top of the mercury at CD. We then plunged the whole apparatus into an iron boiler, EFGH, full of boiling sea-water, of the temperature of  $223.25^{\circ}$ , placed upon the furnace GHIK. So soon as the water over the mercury reached the temperature of  $212^{\circ}$ , it began to boil ; and, instead of only filling the small space ACD, it was converted into an aëriform fluid, which filled the whole jar ; the mercury even descended below the surface of that in the dish B ; and the jar must have been overturned, if it had not been very thick and heavy, and fixed to the dish by means of iron-wire. Immediately after withdrawing the apparatus from the boil-

er, the vapour in the jar began to condense, and the mercury rose to its former station; but the water returned again to the æriform state in a few seconds after replacing the apparatus in the boiler.

We have thus a certain number of substances, which are convertible into elastic æriform fluids, by degrees of temperature not much superior to that of our atmosphere. We shall afterwards find, that there are several others which undergo the same change in similar circumstances, such as muriatic or marine acid, ammoniac or volatile alkali, the carbonic acid or fixed air, the sulphurous acid, &c. All these are permanently elastic in or about the mean temperature of the atmosphere, and under its common pressure.

All these facts, which could be easily multiplied, if necessary, give full right to assume, as a general principle, that almost every body in nature is susceptible of three several states of existence, solid, liquid, and æriform; and that these three states of existence depend upon the quantity of caloric combined with the body. Henceforward I shall express these elastic æriform fluids by the generic term *gas*: and in each species of gas I shall distinguish between the caloric, which in some measure serves the purpose of a solvent, and the substance, which, in combination with the caloric, forms the base of the gas.

To these bases of the different gasses, which are hitherto but little known, we have been obliged to assign names. These shall be enumerated in Chap IV. of this work, when I have previously given an account of the phenomena attendant upon the heating and cooling of bodies, and when I have established precise ideas, concerning the composition of our atmosphere.

We have already shewn, that the particles of every substance in nature exist in a certain state of equilibrium, between that attraction which tends to unite and keep the particles together, and the effects of the caloric which tends to separate them. Hence, caloric not only surrounds the particles of all bodies on every side, but fills up every interval which the particles of bodies leave between each other. We may form an idea of this, by supposing a vessel filled with small spherical leaden bullets, among which a quantity of fine sand is poured; this, insinuating itself into the intervals between the bullets, will fill up every void. The balls, in this comparison, are, to the sand which surrounds them, exactly in the same situation as the particles of bodies are with respect to the caloric; with this difference only, that the balls are supposed to touch each other, whereas the particles of bodies are not in contact, being retained at a small distance from each other, by the caloric.

If, instead of spherical balls we substitute solid bodies of a hexahedral, octohedral, or any other regular figure, the capacity of the intervals between them will be lessened, and consequently will no longer contain the same quantity of sand. The same thing takes place with respect to natural bodies. The intervals left between their particles are not of equal capacity, but vary in consequence of the different figures and magnitude of their particles, and of the distance at which these particles are maintained, according to the existing portion between their inherent attraction, and the repulsive force exerted upon them by the caloric.

In this manner we must understand the following expression, introduced by the English philosophers, who have given us the first precise ideas upon this subject; *the capacity of bodies for containing the matter of heat*. As comparisons with sensible objects are of great use in assisting us to form distinct notions of abstract ideas, I shall endeavour to illustrate this, by instancing the phenomena which take place between water and bodies which are wetted and penetrated by it, with a few reflections.

If equal pieces of different kinds of wood, suppose cubes of one foot each, be immersed in water, the fluid gradually insinuates itself into their pores, and the pieces of wood are augmented both in weight and magnitude. Each

species of wood will imbibe a different quantity of water. The lighter and more porous woods will admit a larger; the compact and closer grained will admit a lesser quantity: for the proportional quantities of water, imbibed by the pieces, will depend upon the nature of the constituent particles of the wood, and upon the greater or lesser affinity subsisting between them and water. Very resinous wood, for instance, though it may be at the same time very porous, will admit but little water. We may, therefore, say, that different kinds of wood possess different capacities for receiving water: and we may even determine, by means of the augmentation of their weights, what quantity of water they have actually absorbed: but, as we are ignorant how much water they contained previous to immersion, we cannot determine the absolute quantity they contain after being taken out of the water.

The same circumstances undoubtedly take place with bodies which are immersed in caloric; taking into consideration, however, that water is an incompressible fluid; whereas caloric is, on the contrary, endowed with very great elasticity; or, in other words, the particles of caloric have a great tendency to separate from each other, when forced by any other power to approach. This difference must of necessity occa-



sion very considerable diversities in the results of experiments made upon these two substances.

Having established these clear and simple propositions, it will be very easy to explain the ideas which ought to be affixed to the following expressions, which are by no means synonymous, but possess each a strict and determinate meaning, as in the following definitions :

*Free caloric* is that which is not combined in any manner with any other body. But, as we live in a system to the matter of which caloric has a very strong adhesion, we are never able to obtain it in the state of absolute freedom.

*Combined caloric* is that which is fixed in bodies, by affinity or elective attraction, so as to form part of the substance of the body, even part of its solidity.

By the expression, *specific caloric* of bodies, we understand the respective quantities of caloric requisite for raising a number of bodies of the same weight to an equal degree of temperature. This proportional quantity of caloric depends on the distance between the constituent particles of bodies, and their greater or lesser degrees of cohesion ; and this distance, or rather the space or void resulting from it, is, as I have already observed, called the *capacity of bodies for containing caloric*.

*Heat*, considered as a sensation, or, in other words, sensible heat, is only the effect produced upon our sentient organs, by the motion or passage of caloric, disengaged from the surrounding bodies. In general, we receive impressions only in consequence of motion: and it might be established as an axiom, *That WITHOUT MOTION, THERE IS NO SENSATION.* This general principle applies very accurately to the sensations of heat and cold. When we touch a cold body, the caloric, which always tends to become in equilibrium in all bodies, passes from our hand into the body we touch, which gives us the feeling or sensation of cold. The direct contrary happens, when we touch a warm body: the caloric, then, in passing from the body into our hand, produces the sensation of heat. If the hand and the body touched be of the same temperature, or very nearly so, we receive no impression, either of heat or cold; because there is no motion or passage of caloric; and thus no sensation can take place, without some correspondent motion to occasion it.

When the thermometer rises, it shows, that free caloric is entering into the surrounding bodies. The thermometer, which is one of these, receives its share in proportion to its mass, and to the capacity which it possesses for containing caloric. The change, therefore, which takes place upon the thermometer, only announces a

change of place of the caloric in those bodies, of which the thermometer forms one part. It only indicates the portion of caloric received, without being a measure of the whole quantity disengaged, displaced, or absorbed.

The most simple and most exact method for determining this latter point, is that described by Mr de la Place, in the Memoirs of the Academy, for the year 1780, p. 364: a summary explanation of which will be found towards the conclusion of this work. This method consists in placing a body, or a combination of bodies, from which caloric is disengaging, in the middle of a hollow sphere of ice: and the quantity of ice melted becomes an exact relative measure of the quantity of caloric disengaged. It is possible, by means of the apparatus which we have got constructed upon this plan, to determine, not as has been pretended, the capacity of bodies for containing heat, but the ratio of the increase or diminution of capacity produced by determinate degrees of temperature. It is easy, with the same apparatus, by variously combined experiments, to determine the relative quantities of caloric necessary for converting solid substances into liquids, and liquids into elastic æriform fluids; and *vice versa*, what quantity of caloric escapes from elastic vapours in changing to liquids, and what quantity escapes from liquids during their conversion into solids. Perhaps, when

experiments shall have been made with sufficient accuracy, we may one day be able to determine the proportional quantities of caloric necessary for producing the several species of gasses. I shall hereafter, in a separate chapter, give an account of the principal results of such experiments as have been made upon this head.

It remains, before finishing this article, to say a few words concerning the cause of the elasticity of gasses, and of liquids in the state of vapour. It is by no means difficult to perceive that this elasticity depends upon that of caloric, which seems to be the most eminently elastic body in nature. Nothing is more readily conceivable, than that one body should become elastic, by entering into combination with another body possessed of that quality. We must allow that this is only an explanation of elasticity, by an assumption of elasticity. We thus only remove the difficulty one step farther; and the reason for caloric being elastic, still remains unexplained. Elasticity in the abstract is merely a supposable quality inherent to the particles of bodies, by virtue of which they recede from each other when forced together. This tendency in the particles of caloric to separate, takes place even at considerable distances. We shall be satisfied of this, when we consider, that air is capable of undergoing great compression; which supposes that its particles were previous-

ly at a considerable distance from each other; for the power of approaching toget' er certainly supposes a previous distance, at least equal to the degree of approximation. Consequently, those particles of the air, which are already considerably distant from each other, tend to separate still farther. If we produce Boyle's vacuum in a large receiver of an air-pump, the last portion of air which remains, extends itself uniformly through the whole capacity of the vessel, however large, filling it completely, and pressing every where against its sides. We cannot explain this fact, without supposing that the particles make an effort to separate themselves on every side: and we are quite ignorant at what distance, or in what degree of rarefaction, this effort ceases to act.

In the above experiments, a true repulsion takes place between the particles of elastic fluids. At least, circumstances occur exactly as if such a repulsion actually existed: and we have a right to conclude, that the particles of caloric mutually repel each other. When we are once permitted to suppose this repelling force, the theory of the formation of gasses, or aëriiform fluids, becomes perfectly simple: though we must, at the same time, allow, that it is extremely difficult to form an accurate conception how this repulsive force acts upon very mi-

nute particles placed at great distances from each other.

It is, perhaps, more natural to suppose, that the particles of caloric have a stronger mutual attraction than those of any other substance; and that these latter particles are torn asunder in consequence of this superior attraction of the particles of caloric, which forces them between the particles of other bodies, that they may be able to reunite with each other. We may observe something analogous to this idea in the phenomena which occur when a dry sponge is dipt in water. This sponge swells; its particles separate from each other; and all its intervals are filled by the water. It is evident, that the sponge, in the act of swelling, has acquired a greater capacity\* for containing water than it had when

\* This assertion does not seem well founded:—That, in the act of swelling, the sponge receives more water than it held when dry, is very evident; and that, in consequence of its fibres being stretched, more room is left between them, is likewise true: But if, by capacity for receiving water, we are to understand that quality inherent in the sponge for imbibing water, in consequence of the disposition and peculiar structure of its parts, this remains the same when perfectly dry as when filled completely with moisture; or, if we consider its capacity to indicate its disposition for receiving additional water, this must be greatest when perfectly dry, and must diminish in proportion as the water is received into its interstices.—T.



dry. But we cannot certainly maintain, that the introduction of water between the particles of the sponge has endowed them with a repulsive power, which tends to separate them from each other: on the contrary, the whole phenomena are produced by means of attractive powers: These are, the gravity of the water, and the power which it exerts on every side, in common with all other fluids; the force of attraction, which takes place between the particles of water, causing them to unite together; the mutual attraction of the particles of the sponge for each other; and, the reciprocal attraction which exists between the particles of the sponge and those of the water. It is easy to understand, that the explanation of this fact depends upon properly appreciating the intensity of, and connection between, these several powers. It is probable, therefore, that the separation of the particles of bodies, occasioned by caloric, depends in a similar manner upon a certain combination of different attractive powers, which, in conformity with the imperfection of our knowledge, we endeavour to express by saying, that caloric communicates a power of repulsion to the particles of bodies.

## CHAPTER. II.

*General Views concerning the Formation and Composition of our Atmosphere.*

THESE views which I have taken of the formation of elastic æriform fluids or gasses, throw great light upon the original formation of the atmospheres of the planets, and particularly of that of our earth. We readily conceive, that it must necessarily consist of a mixture of the following substances: Of all bodies that are susceptible of evaporation, or, more strictly speaking, which are capable of retaining the state of æriform elasticity in the temperature of our atmosphere, and under a pressure equal to that of a column of twenty-eight inches of quicksilver in the barometer; and, of all substances, whether liquid or solid, which are capable of being dissolved in this mixture of different gasses.

To fix our ideas more clearly respecting this subject, which has not been hitherto sufficiently considered, let us, for a moment, conceive what change would take place in the various

substances which compose our earth, if its temperature were suddenly altered. If, for instance, we were suddenly transported to the region of the planet Mercury, where probably the common temperature is much superior to that of boiling water; the water of our world, and all the other fluids which are susceptible of the gaseous state, at a temperature near to that of boiling water, even quicksilver itself, would become rarefied: and all these substances, being changed into permanently æriform fluids or gases, would become part of the new atmosphere. These new species of airs or gases would mix with those already existing, and certain reciprocal decompositions and new combinations would take place, until such time as all the elective attractions or affinities subsisting among all these new and old gaseous substances had operated fully; after which, the elementary principles composing these gases, being saturated, would remain at rest.

We must attend to this, however, that, even in the above hypothetical situation, certain bounds would occur to the evaporation of these substances, produced by means of that very evaporation itself. For as, in proportion to the increase of elastic fluids, the pressure of the atmosphere would be augmented—as every degree of pressure tends, in some measure, to prevent evaporation—and as even the most eva-

porable fluids can resist the operation of a very high temperature without evaporating, if prevented by a proportionally stronger compression, water and all other liquids being able to sustain a red heat in Papin's digester; we must admit, that the new atmosphere would at last acquire such a degree of weight, that the water which had not hitherto evaporated, would cease to boil, and, of consequence, would remain liquid. Hence, even upon this supposition, as in all others of the same nature, the increasing gravity of the atmosphere would find certain limits which it could not exceed.

We might extend these reflections greatly farther, and examine what change would be produced in such situations upon stones, salts, and the greater part of the fusible substances which compose the mass of our earth. These would be softened, fused, and changed into liquids, &c. But these speculations carry me from my object, to which I hasten to return.

By a contrary supposition, to the one we have been forming, if the earth were suddenly transported into a very cold region, the water, which at present composes our seas, rivers, and springs, and probably the greater number of the fluids we are acquainted with, would be converted into solid mountains and hard rocks, at first diaphanous and homogeneus, like rock

crystal, but which, in time, becoming mixed with foreign and heterogeneous substances, would become opaque stones of various colours. In this case, the air, or, at least, some of the æriform fluids which now compose the mass of our atmosphere, would doubtless lose their elasticity, for want of a sufficient temperature to retain them in that state. They would return to the liquid state of existence\*: and new liquids would be formed, of whose properties we cannot at present, form the most distant idea.

These two opposite suppositions give a distinct proof of the following corollaries: That *solidity, liquidity, and æriform elasticity*, are only three different states of existence of the same matter, or three particular modifications which almost all substances are susceptible of assuming successively, and which solely depend on the degree of temperature to which they are exposed; or, in other words, upon the quantity of caloric with which they are penetrated†; that it is

\* Even this supposition would have its bounds from its own nature. The diminution of pressure, produced by the decrease in the volume, and consequent gravity, of the atmosphere, would enable caloric to keep many substances in the vaporous state, at a much lower degree of temperature than is fit for that purpose, under the present pressure of our atmosphere.—T.

† The degree of pressure which they undergo must be taken into account.—T.

extremely probable that air is a fluid naturally existing in a state of vapour ; or, as we may better express it, that our atmosphere is a compound of all the fluids which are susceptible of the vaporous or permanently elastic state, in the usual temperature, and under the common pressure ; that it is not impossible we may discover, in our atmosphere, certain substances naturally very compact, even metals themselves ; as a metallic substance, for instance, only a little more volatile than mercury, might exist in that situation.

Among the fluids with which we are acquainted, some, as water and alcohol, are susceptible of mixing with each other in all proportions ; whereas others, as quicksilver, water, and oil, can only form a momentary union, and, after being mixed together, separate and arrange themselves according to their specific gravities. The same ought to, or at least may, take place in the atmosphere. It is possible, and even extremely probable, that, both at the first creation, and every day, gasses are formed, which are difficultly miscible with atmospheric air, and are continually separating from it. If these gasses be specifically lighter than the general atmospheric mass, they must, of course, gather in the higher regions, and form strata that float upon the common air. The phenomena which



accompany igneous metcours, induce me to believe, that there exists, in the upper parts of our atmosphere, a stratum of inflammable fluid, in contact with those strata of air in which the phenomena of the aurora borealis and other fiery appearances are produced.—I mean hereafter to pursue this subject in a separate treatise.

## C H A P. III.

*Analysis of Atmospheric Air, and its Division into two Elastic Fluids; the one fit for Respiration; the other incapable of being respired.*

FROM what has been premised, it appears, that our atmosphere is composed of a mixture of every substance capable of retaining the gaseous or aëriform state in the common temperatures, and under the usual degrees of pressure which it experiences. These fluids constitute a mass, in some measure homogeneous, extending from the surface of the earth to the greatest height hitherto attained, of which the density continually decreases in the inverse ratio of the superincumbent weight. But, as I have before observed, it is possible that this first stratum may be surmounted by several others consisting of different fluids.

Our business, in this place, is to endeavour to determine by experiments, the nature of the elastic fluids which compose the inferior stratum of air which we inhabit. Modern chemistry has made great advances in this research: and it will appear, by the following details, that the analysis of atmospherical air has been more

rigorously determined than that of any other substance of the class.

Chemistry affords two general methods of determining the constituent principles of bodies, the method of analysis, and that of synthesis. When, for instance, by combining water with alcohol, we form the species of liquor called, in commercial language, brandy or spirit of wine, we certainly have a right to conclude, that brandy, or spirit of wine, is composed of alcohol combined with water. We can procure the same result by the analytical method: and in general it ought to be considered as a principle in chemical science, never to rest satisfied without both these species of proofs. We have this advantage in the analysis of atmospheric air; being able both to decompose it, and to form it anew in the most satisfactory manner. I shall, however, at present confine myself to recount such experiments as are most conclusive upon this head: and I may consider most of these as my own, having either first invented them, or having repeated those of others, intended for analysing atmospheric air, in perfectly new points of view.

I took a matrafs of about 36 cubical inches capacity, having a long neck of six or seven lines internal diameter, and having bent the neck, as in Plate IV. Fig. 2. BCDE, to allow of its be-

L

ing placed in the furnace MMNN, in such a manner that the extremity of its neck E might be inserted under a bell-glass F G, placed in a trough of quicksilver RRSS; I introduced four ounces of pure mercury into the matrafs, and by means of a syphon, exhausted the air in the receiver FG, so as to raise the quicksilver to LL; and I carefully marked the height at which it stood, by pasting on a slip of paper. Having accurately noted the height of the thermometer and barometer, I lighted a fire in the furnace MMNN, which I kept up almost continually during twelve days, so as to keep the quicksilver always very near its boiling point. Nothing remarkable took place during the first day. The mercury, though not boiling, was continually evaporating, and covered the interior surface of the vessel with small drops, which gradually augmenting to a sufficient size, fell back into the mass at the bottom of the vessel. On the second day, small red particles began to appear on the surface of the mercury. These, during the four or five following days, gradually increased in size and number; after which they ceased to increase in either respect. At the end of twelve days, seeing that the calcination of the mercury did not at all increase, I extinguished the fire, and allowed the vessels to cool. The bulk of air in the body and neck of the matrafs, and in the bell-

glafs, reduced to a medium of 28 inches of the barometer and  $54.5^{\circ}$  of the thermometer, at the commencement of the experiment was about 50 cubical inches. At the end of the experiment, the remaining air, reduced to the same medium pressure and temperature, was only between 42 and 43 cubical inches; consequently it had lost about  $\frac{1}{6}$  of its bulk. Afterwards, having collected all the red particles, formed during the experiment, from the running mercury in which they floated, I found these to amount to 45 grains.

I was obliged to repeat this experiment several times; as it is difficult, in one experiment, both to preserve the whole air upon which we operate, and to collect the whole of the red particles, or calx of mercury, which is formed during the calcination. It will often happen in the sequel, that I shall in this manner, give in one detail the results of two or three experiments of the same nature.

The air which remained after the calcination of the mercury in this experiment, and which was reduced to  $\frac{5}{6}$  of its former bulk, was no longer fit either for respiration or for combustion. Animals being introduced into it were suffocated in a few seconds: and when a taper was plunged into it, it was extinguished, as if it had been immersed in water.

In the next place, I took the 45 grains of red matter formed during this experiment, which I put into a small glass retort, having a proper apparatus for receiving such liquid or gaseous product, as might be extracted. Having applied a fire to the retort in the furnace, I observed that, in proportion as the red matter became heated, the intensity of its colour augmented. When the retort was almost red hot, the red matter began gradually to decrease in bulk; and in a few minutes after, it disappeared altogether. At the same time 41  $\frac{1}{2}$  grains of running mercury were collected in the recipient: and 7 or 8 cubical inches of elastic fluid, greatly more capable of supporting both respiration and combustion than atmospherical air, were collected in the bell-glass.

A part of this air being put into a glass tube of about an inch diameter, shewed the following properties: A taper burned in it with a dazzling splendor: and charcoal, instead of consuming quietly as it does in common air, burnt with a flame, attended with a decrepitating noise, like phosphorus; and threw out such a brilliant light that the eyes could hardly endure it. This species of air was discovered almost at the same time by Dr Priestley, Mr Scheele, and myself. Dr Priestley gave it the name of *dephlogisticated air*. Mr Scheele called it *empyreal air*. At first I named it *highly respirable air*, to



which has since been substituted the term of *vital air*. We shall presently see what we ought to think of these denominations.

In reflecting upon the circumstances of this experiment, we readily perceive that, the mercury, during its calcination, absorbs the salubrious and respirable part of the air, or, to speak more strictly, the base of this respirable part; that the remaining air is a species of mephitic, incapable of supporting combustion or respiration; and, consequently, that atmospheric air is composed of two elastic fluids, of different and opposite qualities. As a proof of this important truth, if we recombine these two elastic fluids, which we have separately obtained in the above experiment, viz. the 42 cubical inches of mephitic, with the 8 cubical inches of highly respirable air, we reproduce an air precisely similar to that of the atmosphere, and possessing nearly the same power of supporting combustion and respiration, and of contributing to the calcination of metals.

Although this experiment furnishes us with a very simple means of obtaining the two principal elastic fluids which compose our atmosphere, separate from each other; yet it does not give us an exact idea of the proportion in which these two enter into its composition. For the attraction of mercury to the respirable part of the air, or rather to its base, is not sufficiently strong to overcome all the circumstances which

oppose this union. These obstacles are the mutual adhesion of the two constituent parts of the atmosphere for each other, and the elective attraction which unites the base of vital air with caloric. In consequence of these, when the calcination ends, or is at least carried as far as is possible in a determinate quantity of atmospheric air, there still remains a portion of respirable air united to the mephitic, which the mercury cannot separate. I shall afterwards shew, that at least in our climate, the atmospheric air is composed of respirable and mephitic airs, in the proportion of 27 and 73; and I shall then discuss the causes of the uncertainty which still exists with respect to the exactness of that proportion.

Since, during the calcination of mercury, air is decomposed, and the base of its respirable part is fixed and combined with the mercury, it follows, from the principles already established, that caloric and light must be disengaged during the process. But the two following causes prevent us from being sensible of this taking place; as the calcination lasts during several days, the disengagement of caloric and light, spread out in a considerable space of time, becomes extremely small for each particular moment of the time, so as not to be perceptible; and, the operation being carried on by means of fire in a furnace, the heat produced

by the calcination itself, becomes confounded with that proceeding from the furnace. I might add, that the respirable part of the air, or rather its base, in entering into combination with the mercury, does not part with all the caloric which it contained, but still retains a part of it in the new compound. But the discussion of this point, and its proofs from experiment, do not belong to this part of our subject.

It is, however, easy to render this disengagement of caloric and light evident to the senses, by causing the decomposition of air to take place in a more rapid manner; and for this purpose, iron is excellently adapted, as it possesses a much stronger affinity for the base of respirable air than mercury. The following elegant experiment of Mr Ingenhouz, upon the combustion of iron, is well known. Take a piece of fine iron wire, twisted into a spiral, BC, Plate IV. Fig. 17. fix one of its extremities B into the cork A, adapted to the neck of the bottle DEFG, and fix to the other extremity of the wire C, a small morsel of tinder. Matters being thus prepared, fill the bottle DEFG with air deprived of its mephitic part. Then light the tinder, and introduce it quickly, with the wire upon which it is fixed, into the bottle which you stop up with the cork A, as is shown in the figure 17. Plate IV. The instant the

lighted tinder comes into contact with the vital air, it begins to burn with great intensity; and communicating the inflammation to the iron-wire, it likewise takes fire and burns rapidly, throwing out brilliant sparks. These fall to the bottom of the vessel in rounded globules, which become black in cooling, but retain a degree of metallic splendor. The iron thus burnt is more brittle even than glass; is easily reduced into powder; and is still attractible by the magnet, though not so powerfully as it was before combustion. As Mr. Ingenhouz has neither examined the change produced on the iron, nor upon the air by this operation, I have repeated the experiment under different circumstances, in an apparatus adapted to answer my particular views, as follows.

Having filled a bell-glass A, Plate IV. Fig. 3. of about six pints measure, with pure air, or the highly respirable part of air, I transported this jar, by means of a very flat vessel, into a quicksilver bath, in the basin BC, taking care to render the surface of the mercury perfectly dry, both within and without the jar, with blotting paper. I then provided a small cup of china-ware D, very flat and open, in which I placed some small pieces of iron turned spirally, and arranged in such a way as seemed most favourable for the combustion being communicated to every part. To the end of one of these pieces of iron was

fixed a small morsel of tinder, to which was added about the sixteenth part of a grain of phosphorus: and by raising the bell-glass a little, the china cup, with its contents, were introduced into the pure air. I know that, by this means, some common air must mix with the pure air in the glass: but this, when it is done dextrously, is so very trifling, as not to injure the success of the experiment. This being done, a part of the air was sucked out from the bell-glass, by means of the syphon GHI, so as to raise the mercury within the glass to EF: and, to prevent the mercury from getting into the syphon, a small piece of paper was twisted round its extremity. In sucking out the air, if the motion of the lungs only be used, we cannot make the mercury rise above an inch or an inch and a half. But, by properly using the muscles of the mouth, we can, without difficulty, cause it to rise six or seven inches.

I next took an iron wire, MN, Plate IV. Fig. 16. properly bent for the purpose; and, making it red hot in the fire, passed it through the mercury into the receiver, and brought it in contact with the small piece of phosphorus attached to the tinder. The phosphorus instantly took fire, - which communicated to the tinder, and from that to the iron. When the pieces have been properly arranged, the whole iron burns, even to the last particle, throwing

out a white brilliant light, similar to that of Chinese fireworks. The great heat produced by this combustion melts the iron into round globules of different sizes, most of which fall into the China cup : but some are thrown out of it, and swim on the surface of the mercury. At the beginning of the combustion, there is a slight augmentation in the volume of the air in the bell-glass, from the dilatation caused by the heat. But presently afterwards, a rapid diminution of the air takes place, and the mercury rises in the glass ; inasmuch that, when the quantity of iron is sufficient, and the air operated upon is very pure, almost the whole air employed is absorbed.

It is proper to remark in this place, that, unless in making experiments for the purpose of discovery, it is better to be contented with burning a moderate quantity of iron : for, when this experiment is pushed too far, so as to absorb much of the air, the cup D, which floats upon the quicksilver, approaches too near the bottom of the bell-glass : and the great heat produced, which is followed by a very sudden cooling, occasioned by the contact of the cold mercury, is apt to break the glass : in which case, the sudden fall of the column of mercury, which happens the moment the least flaw is produced in the glass, causes such a wave, as throws a great part of the quicksilver from the



bason. To avoid this inconvenience, and to ensure success to the experiment, one dram and a half of iron is sufficient to burn in a bell-glass, which holds about eight pints of air. The glass ought likewise to be strong, that it may be able to bear the weight of the column of mercury which it has to support.

By this experiment, it is not possible to determine, at one time, both the additional weight acquired by the iron, and the changes which have taken place in the air. If it is wished to ascertain what additional weight has been gained by the iron, and the proportion between that and the air absorbed, we must carefully mark upon the bell-glass, with a diamond, the height of the mercury, both before and after the experiment. After this, the syphon, GH, Pl. IV. Fig. 3. guarded, as before, with a bit of paper, to prevent its filling with mercury, is to be introduced under the bell-glass, having the thumb placed upon the extremity, G, of the syphon, to regulate the passage of the air: and by this means the air is gradually admitted, so as to let the mercury fill to its level. This being done, the bell-glass is to be carefully removed; the globules of melted iron contained in the cup, and those which have been scattered about, and swim upon the mercury, are to be accurately collected; and the whole is to be weighed. The iron will be found in that state called *martial*

*ethiops* by the old chemists, possessing a degree of metallic brilliancy, very friable, and readily reducible into powder, under the hammer, or with a pestle and mortar. If the experiment has succeeded well, from 100 grains of iron will be obtained 135 or 136 grains of *ethiops*, which is an augmentation of 35 per cent.

If all the attention has been paid to this experiment which it deserves, the air will be found diminished in weight, exactly equal to what the iron has gained. Having therefore burnt 100 grains of iron, which has acquired an additional weight of 35 grains, the diminution of air will be found exactly 70 cubical inches: and it will be shewn, in the sequel, that the weight of vital air is very near half a grain for each cubical inch; so that, in effect, the augmentation of weight in the one exactly coincides with the loss of it in the other.

I shall observe here, once for all, that, in every experiment of this kind, the pressure and temperature of the air, both before and after the experiment, must be reduced by calculation, to a common standard of  $54.5^{\circ}$  of the thermometer, and 28 inches of the barometer. Towards the end of this work, the manner of performing this very necessary reduction will be found accurately detailed.

If it be required to examine the nature of the air which remains after this experiment, we

must operate in a somewhat different manner. After the combustion is finished, and the vessels have cooled, we first take out the cup, and the burnt iron, by introducing the hand through the quicksilver, under the bell-glass. We next introduce some solution of potash, or caustic alkali, or of the sulphuret of potash, or such other substances as are judged proper for examining their action upon the residuum of air. I shall, in the sequel, give an account of these methods of analysing air, when I have explained the nature of these different substances, which are only here in a manner incidentally mentioned. After this examination, so much water must be let into the glass as will displace the quicksilver; and then, by means of a shallow dish, placed below the bell-glass, it is to be removed into the common water pneumato-chemical apparatus\*, where the air remaining may be examined at large, and with great facility.

When very soft and very pure iron has been employed in this experiment, and, when the combustion has been performed in the purest respirable or vital air, free from admixture of the noxious or mephitic part, the air which remains

\* For a particular description of this apparatus, and the manner of using it, and of many other processes, with the instruments fitted for carrying them on, see the third part of this work.—T.

after the combustion, will be found as pure as it was before. But it is difficult to find iron entirely free from a small portion of charry matter, which is chiefly abundant in steel: and it is likewise exceedingly difficult to procure pure air perfectly free from some admixture of mephitic, with which it is almost always contaminated. That species of noxious air does not, in the smallest degree, disturb the result of the experiment, as it is always found at the end exactly in the same quantity as at the beginning.

I mentioned before, that we have two ways of determining the constituent parts of atmospheric air, the method of analysis, and that by synthesis. The calcination of mercury has furnished us with an example of each of these methods; since, after having deprived it of the respirable part, by means of the mercury, we have restored it again, so as to recompose an air precisely similar to that of the atmosphere. But we can equally accomplish this synthetic composition of atmospheric air, by borrowing the materials of which it is formed from different kingdoms of nature. We shall see hereafter, that, when animal substances are dissolved in the nitric acid, a great quantity of gas is disengaged, which extinguishes light, and is unfit for animal respiration, being exactly similar to the noxious or mephitic part of atmospheric air.

And, if we take 73 parts, by weight, of this elastic fluid, and mix them with 27 parts of highly respirable air, procured from calcined mercury, we shall form an elastic fluid precisely similar to atmospheric air in all its properties.

There are many other methods of separating the respirable from the noxious part of the atmospheric air, which cannot be taken notice of in this place, without anticipating information, which properly belongs to the subsequent chapters. The experiments already adduced, may suffice for an elementary treatise: and, in matters of this nature, the choice of our evidences is of far greater consequence than their number.

I shall close this article, by pointing out the property possessed by atmospheric air, and all the known gasses, of dissolving water; which circumstance it is of great consequence to attend to in all experiments of this nature. Mr Saussure found, by experiment, that a cubical foot of atmospheric air is capable of holding 12 grains of water in solution\*. Other gasses, as the carbonic acid, appear capable of dissolving a greater quantity: but experiments are still wanting

\* It is evident that the quantity of water held in solution, by determinate quantities of the different gasses, must vary according to the degrees of temperature and pressure.

by which to determine their several proportions. This water, held in solution by gasses, gives rise to particular phenomena, which require great attention, in many experiments, and which have frequently proved the source of great errors to chemists in determining the results of their experiments.



## C H A P. IV.

*Nomenclature of the several Constituent Parts of Atmospheric Air.*

**H**ITHERTO I have been obliged to make use of circumlocution, to express the nature of the several substances which constitute our atmosphere, having provisionally used the terms of *respirable*, and *noxious* or *non-respirable parts of the air*. But the investigations I mean to undertake require a more direct mode of expression; and, having now endeavoured to give simple and distinct ideas of the different substances which enter into the composition of the atmosphere, I shall henceforth express these ideas by words equally simple.

The temperature of our earth being very near to that at which water becomes solid, and at which reciprocally it changes from solid to fluid—and as this phenomenon takes place frequently under our observation—it has very naturally followed, that, in the languages of at least every climate subject to any degree of winter, a term has been used for signifying water in the state of solidity, or when deprived of its ca-

loric. The same precision has not been found necessary with respect to water reduced to the state of vapour by an additional quantity of caloric. Those persons who do not make a particular study of objects of this kind, are still ignorant that water, when in a temperature only a little above the boiling heat, is changed into an elastic aëriform fluid, susceptible, like all other gasses, of being received and contained in vessels, and of preserving its gaseous form so long as it remains at the temperature of  $212^{\circ}$ , and under a pressure not exceeding 28 inches of the mercurial barometer. As this phenomenon has not been very generally observed, no language has used a particular term for expressing water in this state\*: and the same thing occurs with all fluids, and all substances, which do not evaporate in the common temperature, and under the usual pressure of our atmosphere.

For similar reasons, names have not been given to the liquid or concrete states of most of the aëriform fluids. These were not known to arise from the combination of caloric with certain bases: and, as they had not been seen either in the liquid or solid states, their existence, under these forms, was even unknown to natural philosophers.

\* In English, the word *steam* is exclusively appropriated to water in the state of vapour.—T.

We have not pretended to make any alteration upon such terms as are sanctified by ancient custom; and, therefore, continue to use the words *water* and *ice* in their common acceptation. We likewise retain the word *air*, to express that collection of elastic fluids which composes our atmosphere. But we have not thought it necessary to preserve the same respect for modern terms, adopted by the latter philosophers, having considered ourselves as at liberty to reject such as appeared liable to give erroneous ideas of the substances they are meant to express, and either to substitute new terms, or to employ the old ones, after having modified them in such a manner as to convey more determinate ideas. New words, when necessary, have been borrowed chiefly from the Greek language, in such a manner as to make their etymology convey some idea of what was meant to be represented by them: and we have always endeavoured to make these short, and of such a form as to admit of being changed into adjectives and verbs.

Following these principles, we have, after the example of Mr Macquer, retained the term *gas*, employed by Van Helmont; having arranged the numerous class of elastic aeriform fluids under that name, excepting only atmospheric air. *Gas*, therefore, in our nomenclature, becomes a generic term, expressing the fullest degree of saturation in any body with caloric; be-

ing, in fact, a term expressive of a mode of existence. To distinguish the species of gas, we employ a second term derived from the name of the base, which, saturated with caloric, forms each particular gas. Thus, we name water combined to saturation with caloric, so as to form an elastic fluid, *aqueous gas*; ether, combined in the same manner, *ethereal gas*; the combination of alcohol with caloric, becomes *alcoholic gas*; and, following the same principles, we have *muratic acid gas*, *ammoniacal gas*, and so on of every substance susceptible of being combined with caloric, in such a manner as to assume the gaseous or elastic aëriform state.

We have already seen, that the atmospheric fluid, or common air, is composed of two gasses, or aeriform fluids; one of which is capable, by respiration, of contributing to support animal life; and in it metals are calcinable, and combustible bodies may burn. The other, on the contrary, is endowed with directly opposite qualities. It cannot be breathed\* by animals, neither will it admit of the combustion of inflammable bodies, nor of the calcination of metals. We have given to the base of the former, which is the respirable portion of atmospheric air, the

\* It may indeed be inspired into the lungs of animals, but is then sure to produce instant death.—T.

name of *oxygen*, from  $\sigma\chi\upsilon\varsigma$ , *acidum*, and  $\gamma\iota\gamma\gamma\alpha\iota$  *gignor*, because one of the most general properties of this base is to form acids, by combining with many different substances. The union of this base with caloric, which is the same with what was formerly named *pure*, or *vital*, or *highly respirable air*, we now call *oxygen gas*. The weight of this gas, at the temperature of  $54.50^{\circ}$ , and under a pressure equal to 28 inches of the barometer, is half a grain for each cubical inch nearly, or one ounce and a half to each cubical foot.

The chemical properties of the noxious portion of atmospheric air being hitherto but little known, we have been satisfied to derive the name of its base from its known quality of killing such animals as are forced to breathe it; giving it the name of *azot*, from the Greek privative particle  $\alpha$  and  $\zeta\alpha\iota$ , *vita*; hence the name of the noxious part of atmospheric air is *azotic gas*. The weight of this, in the same temperature, and under the same pressure, is 1 oz. 2 drams and 48 grs. to the cubical foot, or 0.4444 of a grain to the cubical inch. We cannot deny, that this name appears somewhat extraordinary. But this must be the case with all new terms, which cannot be expected to become familiar until they have been some time in use. We long endeavoured to find a more proper designation without success. It was at first proposed to call it *alkaligen gas*, as, from

the experiments of Mr Berthollet, it appears to enter into the composition of ammoniac, or volatile alkali. But then, we have as yet no proof of its making one of the constituent elements of the other alkalies; besides, it is proved to form a part of the nitric acid, which gives as good reason to have it called *nitrogen*. For these reasons, finding it necessary to reject any name upon systematic principles, we have considered that we run no risk of mistake in adopting the terms of *azot*, and *azotic gas*, which only express a matter of fact, or that property which it possesses, of depriving such animals as breathe it of their lives.

I should anticipate subjects more properly reserved for the subsequent chapters, were I in this place to enter upon the nomenclature of the several species of gasses. It is sufficient, in this part of the work, to establish the principles upon which their denominations are founded. The principal merit of the nomenclature we have adopted is, that, when once the simple elementary substance is distinguished by an appropriate term, the names of all its compounds derive readily, and necessarily, from this first denomination.



## C H A P. V.

*Of the Decomposition of Oxygen Gas by Sulphur, Phosphorus, and Carbon—and of the Formation of Acids in general.*

**I**N performing experiments, it is a necessary principle, which ought never to be deviated from, that they be simplified as much as possible, and that every circumstance capable of rendering their results complicated, be carefully removed. Wherefore, in the experiments which form the object of this chapter, I have never employed atmospheric air, which is not a simple substance. It is true, that the azotic gas, which forms a part of its mixture, appears to be merely passive during combustion and calcination. But, besides that it retards these operations very considerably, we are not certain but it may even alter their results in some circumstances; for which reason, I have thought it necessary to remove even this possible cause of doubt, by making use only of pure oxygen gas in the following experiments, which shew the effects produced by combustion in that gas. I shall advert to such differences as take place in the results of these, when the oxygen gas, or pure

vital air, is mixed, in different proportions, with azotic gas.

Having filled a bell-glass, A, Pl. IV. fig. 3. of between five and six pints measure, with oxygen gas, I removed it from the water-trough, where it was filled, into the quicksilver bath, by means of a shallow glass dish slipped underneath; and having dried the mercury, I introduced  $61\frac{1}{4}$  grains of Kunkel's phosphorus in two little China cups, like that represented at D, fig. 3. under the glass A. That I might set fire to each of the portions of phosphorus separately, and to prevent the one from catching fire from the other, one of the dishes was covered with a flat piece of glass. I next raised the quicksilver in the bell-glass up to EF, by sucking out a sufficient portion of gas through the syphon GHI. After this, by means of the crooked iron wire, fig. 16. made red hot, I set fire to the two portions of phosphorus successively, first burning that portion which was not covered by the piece of glass. The combustion was extremely rapid, being attended by a very brilliant flame, and a considerable disengagement of light and heat. In consequence of the great heat induced, the gas was at first much dilated; but soon after the mercury returned to its level, and a considerable absorption or diminution of gas took place; at the same time, the whole in-

side of the glass became covered with light white flakes of concrete phosphoric acid.

At the beginning of the experiment, the quantity of oxygen gas, reduced, as before directed, to a common standard of thermometrical temperature and barometrical pressure, amounted to 162 cubical inches; and, after the combustion was finished, only  $23\frac{1}{4}$  cubical inches, likewise reduced to the standard, remained; so that the quantity of oxygen gas absorbed during the combustion was  $138\frac{1}{4}$  cubical inches, equal to 69.375 grains.

A part of the phosphorus remained unconsumed in the bottom of the cups, which being washed on purpose to separate the acid, weighed about  $16\frac{1}{4}$  grains; so that about 45 grains of phosphorus had been consumed. But, as it is hardly possible to avoid an error of one or two grains, I leave the number so far qualified. Hence, as nearly 45 grains of phosphorus had, in this experiment, united with 69.375 grains of oxygen, and as no gravitating matter could have escaped through the glass, we have a right to conclude, that the weight of the substance resulting from the combustion in form of white flakes, must equal that of the phosphorus and oxygen employed, which amounts to 114.375 grains. And we shall presently find, that these flakes consisted entirely of a solid or concrete acid. When we reduce these weights to hun-

dredth parts, it will be found that 100 parts of phosphorus require 154 parts of oxygen for saturation ; and that this combination will produce 254 parts of concrete phosphoric acid, in form of white fleecy flakes.

This experiment proves, in the most convincing manner, that at a certain degree of temperature, oxygen possesses a stronger elective attraction, or affinity, for phosphorus than for caloric ; and that, in consequence of this, the phosphorus attracts the base of oxygen gas from the caloric, which, being set free, spreads itself over the surrounding bodies. But, though this experiment be so far perfectly conclusive, it is not sufficiently rigorous ; for, in the apparatus described above, it is impossible to ascertain the weight of the flakes of concrete acid which are formed : we can therefore only determine this by calculating the weights of oxygen and phosphorus employed. But as, in physics, and in chemistry, it is not allowable to suppose what is capable of being ascertained by direct experiment, I thought it necessary to repeat this experiment, as follows, upon a larger scale, and by means of a different apparatus.

I took a large glass balloon A, Pl. IV. fig. 4. with an opening of three inches diameter, to which was fitted a crystal stopper, ground with emery, and pierced with two holes for the tubes yyy, xxx. Before shutting the balloon with its

stopper, I introduced the support BC, surmounted by the china cup D, containing 150 grs of phosphorus. The stopper was then fitted to the opening of the balloon, luted with fat lute, and covered with slips of linen spread with quicklime, and white of eggs. When the lute was perfectly dry, the weight of the whole apparatus was determined to within a grain, or a grain and a half. I next exhausted the balloon, by means of an air-pump applied to the tube xxx, and then introduced oxygen gas by means of the tube yyy, which has a stop-cock adapted to it. This kind of experiment is most readily and most exactly performed by means of the hydro-pneumatic machine described by Mr Meusnier and myself, in the Memoirs of the Academy for 1782, page 466, and explained in the latter part of this work, with several important additions and corrections since made to it by Mr Meusnier. With this instrument we can readily ascertain, in the most exact manner, both the quantity of oxygen gas introduced into the balloon, and the quantity consumed during the course of the experiment.

When all things were properly disposed, I set fire to the phosphorus with a burning-glass: The combustion was extremely rapid, accompanied with a bright flame, and much heat. As the operation went on, large quantities of white flakes gradually attached themselves to the in-



ner surface of the balloon, until at last it was rendered quite opaque. The quantity of these flakes at the end became so abundant, that, though fresh oxygen gas was continually supplied, which ought to have supported the combustion, the phosphorus became extinguished. Having allowed the apparatus to cool completely, I first ascertained the quantity of oxygen gas employed, and weighed the balloon accurately, before it was opened. I next washed, dried, and weighed the small quantity of phosphorus remaining in the cup, on purpose to determine the whole quantity of phosphorus consumed in the experiment. This residuum of the phosphorus was of a yellow ochrey colour. It is evident, that by these several precautions, I could easily determine the weight of the phosphorus consumed; the weight of the flakes produced by the combustion; and the weight of the oxygen which had combined with the phosphorus.

This experiment gave very nearly the same results with the former; as it proved that the phosphorus, during its combustion, had absorbed a little more than one and a half its weight of oxygen: and I learned with more certainty, that the weight of the new substance, produced in the experiment, exactly equalled the sum of the weights of the phosphorus consumed, and oxygen absorbed; which indeed was easily



determinable *a priori*. If the oxygen gas employed be pure, the residuum after combustion is as pure as the gas employed. This proves that nothing escapes from the phosphorus, capable of altering the purity of the oxygen gas, and that the only action of the phosphorus is to separate the oxygen from the caloric, with which it was before united.

I mentioned above, that when any combustible body is burnt in a hollow sphere of ice, or in an apparatus properly constructed upon that principle, the quantity of ice melted during the combustion is an exact measure of the quantity of caloric disengaged. On this subject the memoir given to the academy by M. de la Place and myself, A°. 1780, p. 355, may be consulted. Having submitted the combustion of phosphorus to this trial, we found that one pound of phosphorus melted a little more than 100 pounds of ice during its combustion.

The combustion of phosphorus succeeds equally well in atmospheric air as in oxygen gas, with this difference, that the combustion is vastly slower, being retarded by the large proportion of azotic gas mixed with the oxygen gas; and that only about one fifth-part of the air employed is absorbed; because, as the oxygen gas only is absorbed, the proportion of the azotic gas becomes so great towards the close of the experiment, as to put an end to the combustion.

I have already shewn, that phosphorus is changed by combustion into an extremely light, white, flakey matter. Its properties are likewise entirely altered by this transformation. From being insoluble in water, it becomes not only soluble, but so greedy of moisture, as to attract the humidity of the air with astonishing rapidity. By this means it is converted into a liquid, considerably more dense, and of more specific gravity than water. In the state of phosphorus before combustion, it has scarcely any sensible taste; by its union with oxygen it acquires an extremely sharp and sour taste. In a word, from one of the class of combustible bodies, it is changed into an incombustible substance, and becomes one of those bodies called acids.

This property of a combustible substance to be converted into an acid, by the addition of oxygen, we shall presently find belongs to a great number of bodies: wherefore, a strict logic requires that we should adopt a common term for indicating all these operations which produce analogous results. This is the true way to simplify the study of science, as it would be quite impossible to bear all its specific details in the memory, if they were not classically arranged. For this reason, we shall distinguish the conversion of phosphorus into an acid, by its union with oxygen, and in general every combination of oxygen with a combustible sub-

stance, by the term of *oxygenation*: From this I shall adopt the verb to *oxygenate*; and of consequence shall say, that in *oxygenating* phosphorus we convert it into an acid.

Sulphur is likewise a combustible body; or, in other words, it is a body which possesses the power of decomposing oxygen gas, by attracting the oxygen from the caloric with which it was combined. This can very easily be proved, by means of experiments quite similar to those we have given with phosphorus. But it is necessary to premise, that in these operations with sulphur, the same accuracy of result is not to be expected as with phosphorus; because the acid which is formed by the combustion of sulphur is difficultly condensable; and because sulphur burns with more difficulty, and is soluble in the different gasses. But I can safely assert, from my own experiments, that sulphur in burning absorbs oxygen gas; that the resulting acid is considerably heavier than the sulphur burnt; that its weight is equal to the sum of the weights of the sulphur which has been burnt, and of the oxygen absorbed; and lastly, that this acid is weighty, incombustible, and miscible with water in all proportions. The only uncertainty remaining on this head, is with regard to the proportions of sulphur and of oxygen which enter into the composition of the acid.

Charcoal, which, from all our present knowledge regarding it, must be considered as a simple combustible body\*, has likewise the property of decomposing oxygen gas, by absorbing its base from the caloric. But the acid resulting from this combustion does not condense in the common temperature. Under the pressure of our atmosphere, it remains in the state of gas, and requires a large proportion of water to combine with, or be dissolved in. This acid has, however, all the known properties of other acids, though in a weaker degree; and combines, like them with all the bases which are susceptible of forming neutral salts.

The combustion of charcoal in oxygen gas, may be effected like that of phosphorus in the bell-glass, A, Pl. IV. fig. 3. placed over mercury. But, as the heat of red-hot iron is not sufficient to set fire to the charcoal, we must add a small morsel of tinder, with a minute particle of phosphorus, in the same manner as is directed in the experiment for the combustion of iron. A detailed account of this experiment will be found in the memoirs of the academy

\* This assertion is to be understood of the pure combustible part of charcoal, which, in the nomenclature, is named carbon, *carbonum*, to distinguish it from charcoal, charbon, *carbo*. The latter, besides carbon, contains some incombustible earth, and certain salts.—T.

for 1781, p. 448. By that experiment it appears, that 28 parts by weight of carbon require 72 parts of oxygen for saturation; and that the æriform acid produced is precisely equal in weight to the sum of the weights of the charcoal consumed, and oxygen gas employed, during the combustion. This æriform acid was called fixed or fixable air by the chemists who first discovered it. They did not then know whether it was air resembling that of the atmosphere, or some other elastic fluid, vitiated and corrupted by combustion. But since it is now ascertained to be an acid, formed like all others by the oxygenation of its peculiar base, it is obvious that the name of fixed air is quite ineligible\*.

By burning charcoal in the apparatus mentioned, p. 60, Mr de la Place and I found that one *lb.* of charcoal melted 96.375*lbs.* of ice; that, during the combustion, 2.5714 *lbs.* of oxygen were absorbed; and that 3.5714 *lbs.* of acid gas were formed. This gas weighs 0.695 parts of a grain for each cubical inch, in the common

P

\* It may be proper to remark, though here omitted by the author, that, in conformity with the general principles of the new nomenclature, this acid is by Mr. Lavoisier and his colleagues called the carbonic acid, and when in the æriform state, carbonic acid gas.—T.

standard temperature and pressure mentioned above ; so that 34242\* cubical inches of acid gas are produced by the combustion of one pound of charcoal.

I might multiply these experiments, and show, by a numerous succession of facts, that all acids are formed by the combustion of certain substances. But I am prevented from doing so in this place, by the plan which I have laid down, of proceeding only from facts already ascertained to such as are unknown, and of drawing my examples only from circumstances already explained. In the mean time, however, the three examples above cited, may suffice for giving a clear and accurate conception of the manner in which acids are formed. By these it may be clearly seen, that oxygen is an element common to them all, and which constitutes or produces their acidity ; and that they differ from each other, according to the several natures of the oxygenated or acidified substances. We must, therefore, in every acid, care-

\* Some error must have crept into Mr. Lavoisier's calculation ; for, on the data here given, the number of cubical inches of gas ought to have been 47358.3 ; as 3.5714 lbs. of carbonic acid gas, or 32914.0224 grs. when divided by .695, the weight of a cubical inch, give this corrected quotient.——T.



fully distinguish between the acidifiable base, which Mr de Morveau calls the radical, and the acidifying principle, or oxygen.

## CHAP VI.

*Of the Nomenclature of Acids in general, and particularly of those drawn from Nitre and Sea-Salt.*

IT becomes extremely easy, from the principles laid down in the preceding chapter, to establish a systematic nomenclature for the acids. The word *acid* being used as a generic term, each acid falls to be distinguished in language, as in nature, by the name of its base or radical. Thus, we give the generic name of acids to the products of the combustion or oxygenation of phosphorus, of sulphur, and of carbon; and these products are respectively named, the *phosphoric acid*, the *sulphuric acid*, and the *carbonic acid*.

There is, however, a remarkable circumstance in the oxygenation of combustible bodies, and of a part of such bodies as are convertible into acids, that they are susceptible of different degrees of saturation with oxygen; and that the resulting acids, though formed by the union of the same elements, are possessed of different properties, depending upon that difference of proportion. Of this, the phosphoric

acid, and, more especially, the sulphuric, furnish us with examples. When sulphur is combined with a small proportion of oxygen, it forms, in the first or lower degree of oxygenation, a volatile acid, having a penetrating odour, and possessed of very peculiar qualities. By a larger proportion of oxygen, it is changed into a fixed, heavy acid, without any odour, and which, by combination with other bodies, gives products quite different from those furnished by the former. In this instance, the principles of our nomenclature seem to fail: and it appears difficult to derive such terms from the name of the acidifiable base, as shall distinctly express these two degrees of saturation, or oxygenation, without circumlocution. By reflection, however, upon the subject, or perhaps rather from the necessity of the case, we have thought it allowable to express these varieties in the oxygenation of the acids, by simply varying the termination of their specific names. The volatile acid produced from sulphur was anciently known to Stahl under the name of *sulphurous acid* \*.

\* The term formerly used by the English chemists for this acid was written *sulphureous*; but I have thought proper to spell it as above, that it may better conform with the similar terminations of *nitrous*, *carbonous*, &c. to be used hereafter. In general, I have used the English terminations *ic* and *ous* to translate the terms of the Author which end with *ique* and *eux*, with hardly any other alterations.—T.

We have preserved that term for this acid from sulphur under-saturated with oxygen; and distinguish the other, or completely saturated or oxygenated acid, by the name of *sulphuric acid*. We shall therefore say, in this new chemical language, that sulphur, in combining with oxygen, is susceptible of two degrees of saturation; that the first or lesser degree, constitutes sulphurous acid, which is volatile and penetrating; while the second, or higher degree of saturation, produces sulphuric acid, which is fixed and inodorous. We shall adopt this difference of termination for all the acids which assume several degrees of saturation. Hence we have a phosphorus and a phosphoric acid, an acetous and an acetic acid; and so on, for others in similar circumstances.

This part of chemical science would have been extremely simple, and the nomenclature of the acids would not have been at all perplexed, as it is now in the old nomenclature, if the base or radical of each acid had been known when the acid itself was discovered. Thus, for instance, phosphorus being a known substance before the discovery of its acid, this latter was rightly distinguished by a term drawn from the name of its acidifiable base. But when, on the contrary, an acid happened to be discovered before its base, or rather, when the acidifiable base from which it was formed, remained un-

known, names were adopted for the two which have not the smallest connection: and thus, not only the memory became burdened with useless appellations, but the minds of students, nay even of experienced chemists, became filled with false ideas, which time and reflection alone are capable of eradicating. We may give an instance of this confusion with respect to the acid of sulphur. The former chemists, having procured this acid from the vitriol of iron, gave it the name of the vitriolic acid from the name of the substance which produced it: and they were then ignorant that the acid procured from sulphur by combustion was exactly the same. The same thing happened with the aëriform acid, formerly called *fixed air*. It not having been known, that this acid was the result of combining carbon with oxygen, a variety of denominations have been given to it, not one of which conveys just ideas of its nature or origin.

We have found it extremely easy to correct and modify the ancient language with respect to those acids which proceed from known bases; having converted the name of *vitriolic acid* into that of *sulphuric*, and the name of *fixed air* into that of *carbonic acid*. But it is impossible to follow this plan with the acids whose bases are still unknown. With these we have been obliged to use a contrary plan, and, instead of

forming the name of the acid from that of its base, have been forced to denominate its unknown base from the name of the known acid, as happens in the case of the acid which is procured from sea salt.

To disengage this acid from the alkaline base with which it is combined, we have only to pour sulphuric acid upon sea-salt. Immediately a brisk effervescence takes place, white vapours arise, of a very penetrating odour, and, by gently heating the mixture, all the acid is driven off. As, in the common temperature and pressure of our atmosphere, this acid is naturally in the state of gas, we must use particular precautions for retaining it in proper vessels. For small experiments, the most simple and most commodious apparatus consists of a small retort G, Pl. V. fig. 5. into which the sea-salt is introduced, well dried\*: we then pour on some concentrated sulphuric acid, and immediately introduce the beak of the retort under little jars or bell-glasses A, same Plate and Fig. previously filled with quicksilver. In proportion as the acid gas is disengaged, it passes into the jar, and gets to the top of the quicksilver which it dis-

\* For this purpose, the operation called *decrepitation* is used, which consists in subjecting it to nearly a red heat, in a proper vessel, so as to evaporate all its water of crystallization.—T.



places. When the disengagement of the gas slackens, a gentle heat is applied to the retort, and is gradually increased, till nothing more passes over. This acid gas has a very strong affinity with water, which absorbs an enormous quantity of it. This is proved by introducing a very thin layer of water into the glass which contains the gas; for, in an instant, the whole acid gas disappears, and combines with the water.

This latter circumstance is taken advantage of in laboratories and manufactories, on purpose to obtain the acid of sea-salt in a liquid form; and for this purpose the apparatus Pl. IV. Fig. 1. is employed. It consists of a tubulated retort *A*, into which the sea-salt, and after it the sulphuric acid, are introduced through the opening *H*; of the balloon or recipient *c, b*, intended for containing the small quantity of liquid which passes over during the process; and of a set of bottles with two mouths, *L, L, L, L*, half filled with water, intended for absorbing the gas disengaged by the distillation. This apparatus will be more amply described in the latter part of this work.

Although we have not yet been able, either to compose or to decompose this acid of sea-salt, we cannot have the smallest doubt that, like all other acids, it is composed by the union of oxygen with an acidifiable base. We have therefore called this unknown substance the

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*muriatic base*, or *muriatic radical*, deriving this name, after the example of Mr Bergman and Mr de Morveau, from the Latin word *muria*, which was anciently used to signify sea-salt. Thus, without being able exactly to determine the component parts of *muriatic acid*, we design by that term a volatile acid, which retains the form of gas in the common temperature and pressure of our atmosphere; which combines with great facility, and in great quantity, with water; and whose acidifiable base adheres so very intimately with oxygen, that no method has hitherto \* been devised for separating them. If ever this acidifiable base of the muriatic acid is discovered to be a known substance, though now unknown in that capacity, it will be requisite to change its present denomination for one analogous with that of its base.

\* Dr. Girtanner is said to have lately discovered that Hydrogen is the base or radical of this acid. Should this discovery be confirmed, the terms will here require some farther alteration, in conformity with the general principles of the new nomenclature. At any rate, *muriogen* may be employed to denominate the base of the muriatic acid, till its nature be unequivocally determined: and, if the discovery attributed to Dr. Girtanner be ascertained, the common base of water and muriatic acid will more properly fall to be named by this new term, than by that of Hydrogen.—T.

In common with sulphuric acid, and several other acids, the muriatic is capable of different degrees of oxygenation : but the excess of oxygen produces quite contrary effects upon it from what the same circumstance produces upon the acid of sulphur. The lower degree of oxygenation converts sulphur into a volatile gaseous acid, which only mixes in small proportions with water ; while a higher oxygenation forms an acid possessing much stronger acid properties, which is very fixed, and cannot remain in the state of gas but in a very high temperature, which has no smell, and which mixes in large proportion with water. With muriatic acid, the direct reverse takes place. An additional saturation with oxygen renders it more volatile, of a more penetrating odour, less miscible with water, and diminishes its acid properties. We were at first inclined to have denominated these two degrees of saturation in the same manner as we had done with the acid of sulphur, calling the less oxygenated *muriatous acid*, and that which is more saturated with oxygen, *muriatic acid* : But, as this latter gives very particular results in its combinations, and as nothing analogous to it is yet known in chemistry, we have left the name of muriatic acid to the less saturated, and give the latter the

more compounded appellation of *oxygenated muriatic acid*\*.

Although the base or radical of the acid which is extracted from nitre or saltpetre be better known, we have judged proper only to modify its name in the same manner with that of the muriatic acid. It is procured from nitre, by the intervention of sulphuric acid, by a process similar to that described for extracting the muriatic acid, and by means of the same apparatus, Pl. IV. Fig 1. In proportion as the acid passes over, it is in part condensed in the balloon or recipient; and the rest is absorbed by the water contained in the bottles L, L, L, L; the water becomes first green, then blue, and at last yellow, in proportion to the concentration of the acid. During this operation, a large quantity of oxygen gas, mixed with a small proportion of azotic gas, is disengaged.

This acid, like all others, is composed of oxygen, united to an acidifiable base, and is even the first acid in which the existence of oxygen

\* The compound term *murioxic acid* might serve very conveniently for expressing this state of the muriatic acid. In strict conformity with the general principles of the new chemical philosophy and its nomenclature, it should have been called *super-oxygenated*, instead of *oxygenated muriatic acid*; for all acids are oxygenated.—T.

was well ascertained. Its two constituent elements are but weakly united, and are easily separated, by presenting any substance with which oxygen has a stronger affinity than with the acidifiable base peculiar to this acid. By some experiments of this kind, it was first discovered that azot, or the base of mephitic or of azotic gas, constituted its acidifiable base or radical; and consequently that the acid of nitre was really an azotic acid, having azot for its base, combined with oxygen. For these reasons, that we might be consistent with our principles, it appeared necessary, either to call the acid *azotic*, or to name the base *nitric radical*; but from either of these we were dissuaded, by the following considerations. It seemed difficult to change the name of nitre or saltpetre, which have been universally adopted in society, in manufactures, and in chemistry; and, on the other hand, azot having been discovered by Mr. Berthollet to be the base of volatile alkali, or ammoniac, as well as of this acid, we thought it improper to call it nitric radical. We have therefore continued the term of azot to the base of that part of atmospheric air which is likewise the nitric and ammoniacal radical; and we have named the acid of nitre, in its lower and higher degrees of oxygenation, *nitrous acid* in the for-

mer, and *nitric acid* in the latter state ; thus preserving its former appellation properly modified.

Several very respectable chemists have disapproved of this deference for the old terms, and wished us to have persevered in perfecting a new chemical language, without paying any respect to ancient usage ; so that, by thus steering a sort of middle course, we have exposed ourselves to the censures of one sect of chemists, and to the expostulations of the opposite party.

The acid of nitre is susceptible of assuming a great number of separate states, depending upon its degree of oxygenation, or upon the proportions in which azot and oxygen enter into its composition. By a first or lowest degree of oxygenation, it forms a particular species of gas, which we shall continue to name *nitrous gas* ; this is composed nearly of two parts, by weight, of oxygen combined with one part of azot ; and in this state it is not miscible with water. In this gas, the azot is by no means fully saturated with oxygen ; but, on the contrary, has still a very great affinity for that element, and even attracts it from atmospheric air, immediately upon getting into contact with it. This combination of nitrous gas with the oxygen gas contained in atmospheric air, has even become



one of the methods for determining the quantity of oxygen gas mixed with any portion of air; and consequently is used as a test for ascertaining its degree of salubrity,

The further addition of oxygen converts the nitrous gas into a powerful acid, which has a strong affinity with water, and which is itself susceptible of various additional degrees of oxygenation. When the proportions of oxygen and azot are below three parts, by weight, of the former, to one of the latter, the acid is red coloured, and emits copious fumes. In this state, by the application of a gentle heat, it gives out nitrous gas; and we term it, in this degree of oxygenation, *nitrous acid*. When four parts, by weight, of oxygen, are combined with one part of azot, the acid is clear and colourless; more fixed in the fire than the nitrous acid; has less odour, and its constituent elements are more firmly united. This species of acid, in conformity with our principles of nomenclature, is called *nitric acid*.

Thus, nitric acid is the acid of nitre, surcharged with oxygen: nitrous acid is the acid of nitre surcharged with azot, or, what is the same thing, with nitrous gas: and this latter is azot not sufficiently saturated with oxygen to possess the properties of an acid. To this lat-

ter degree of oxygenation, we have afterwards, in the course of this work, given the generical name of *oxyd*\*.

\* In strict conformity with the principles of the new nomenclature, but which the author has given his reasons for deviating from in this instance, the following ought to have been the terms for azot, in its several degrees of oxygenation: Azot, azotic gas, (azot combined with caloric), azotic oxyd gas, azorous acid, and azotic acid.——T.

## C H A P. VII.

*Of the Decomposition of Oxygen Gas by means of Metals, and the Formation of Metallic Oxyds.*

OXYGEN has a stronger affinity with metals that are heated to a certain degree, than with caloric. In consequence of this, all metallic bodies, excepting gold, silver, and platinum, have the property of decomposing oxygen gas, by attracting its base from the caloric with which it is combined. We have already shown in what manner this decomposition is effected by means of mercury and iron; having observed, that, in the case of the first, it must be considered as a kind of gradual combustion, whereas, in the latter, the combustion is extremely rapid, and is attended with a brilliant flame. The use of the heat employed in these operations is to separate the particles of the metal from each other, and to diminish their affinity of cohesion or aggregation, or, what is the same thing, their mutual attraction for each other.

The absolute weight of all metallic substances is augmented in proportion to the quantity

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of oxygen they absorb ; they, at the same time, lose their metallic splendor, and are reduced to the appearance of an earthy pulverulent matter : In this state, metals must not be considered as entirely saturated with oxygen, because their action upon this element is counterbalanced by the power of affinity between it and the caloric. During the calcination of metals, the oxygen is therefore acted upon by two separate and opposite powers, that of its attraction for caloric, and that exerted by the metal ; and it only tends to unite with the metal in consequence of the excess of the latter power over the former, which is, in general, very inconsiderable. Wherefore, when metallic substances are oxygenated in atmospheric air, or in oxygen gas, they are not converted into acids, like sulphur, phosphorus, and carbon, but are only changed into intermediate substances, which, though approaching to the nature of salts, have not acquired all the saline properties.

The older chemists have affixed the name of *calx* not only to metals in this state, but to every body which has been long exposed to the action of fire without being melted. They have employed this word *calx* as a generic term ; under which they confound calcareous earth, which, from a neutral salt, which it really was before calcination, has been chan-

ged by fire into an earthy alkali, by *losing* half of its weight ; and metals, which, by the same means, have joined themselves to a new substance, the added quantity of which often *exceeds* half their weight, and by the addition of which they had been changed almost into the nature of acids. This mode of classifying substances, of so very opposite natures, under the same generic name, would have been quite contrary to our principles of nomenclature ; especially as, by retaining the above term for this state of metallic substances, we must have conveyed very false ideas of its nature. We have, therefore, laid aside the expression *metallic calx* altogether, and have substituted in its place the term *oxyd*, from the Greek word *οξύς*.

By this readiness for supplying apposite terms, it is evident that the language we have adopted is both copious and expressive. The first or lowest degree of oxygenation in bodies, converts them into *oxyds* ; a second degree of additional oxygenation constitutes that class of acids, of which the specific names, drawn from their particular bases, terminate in *ous*, as the *nitrous* and *sulphurous* acids ; the third degree of oxygenation changes these into that division of acids, which are distinguished by the termination in *ic*, as the *nitric* and *sulphuric* acids ; and lastly, we can express a fourth, or highest degree of oxygenation, by adding the word *oxy-*

generated to the name of the acid, as has been already done with the *oxygenated muriatic* acid.

We have not confined the term *oxyd* to the purpose of expressing the combination of metals with oxygen, but have extended it to signify that first degree of oxygenation in all bodies, which, without converting them into acids, causes them to approach to the nature of salts. Thus, we give the name of *oxyd of sulphur* to that soft substance into which sulphur is converted by incipient, or imperfect combustion; and we call the yellow matter left by phosphorus, after combustion, by the name of *oxyd of phosphorus*. In the same manner, nitrous gas, which is azot in its first degree of oxygenation, is the *oxyd of azot*\*. We have likewise oxyds in great numbers from the vegetable and animal kingdoms; and I shall shew, in the sequel, that this new language throws great light upon all the operations of art and nature.

We have already observed, that almost all the metallic oxyds have peculiar and perma-

\* Mr. Lavoisier here uses the term *oxyd of azot*, but it is no where else adopted in the new nomenclature; though, as I have mentioned in a former note, it is more legitimate than the term *nitrous gas*; which last he has retained, both because it has long been employed, and chiefly because, as a familiar term in chemistry, it conveys no ideas contradictory to the real nature of the substance it is meant to express.—T.



nent colours. These vary not only in the different species of metals, but even according to the various degrees of oxygenation in the same metal. Hence we are under the necessity of adding two epithets to each oxyd, one of which indicates the metal *oxydated*\*, while the other indicates the peculiar colour of the oxyd. Thus, we have the black oxyd of iron, the red oxyd of iron, and the yellow oxyd of iron; which expressions respectively answer to the old unmeaning terms of martial ethiops, colcothar, and rust of iron, or ochre. We have likewise the grey, yellow, and red oxyds of lead, which answer to the equally false or insignificant old terms, litharge, ashes of lead, massicot, and minium.

These denominations sometimes become rather long, especially when we mean to indicate whether the metal has been oxydated in the air, by detonation with nitre, or by means of acids; but then they always convey just

\* Here we see the word *oxyd* converted into the verb *to oxydate, oxydated, oxydating*, after the same manner with the derivation of the verb *to oxygenate, oxygenated, oxygenating*, from the word *oxygen*. I am not clear of the absolute necessity of this second verb here first introduced, but think that, in a work of this nature, it is the duty of the translator to neglect every other consideration for the sake of strict fidelity to the ideas of his author.—T.

and accurate ideas of the corresponding objects which we wish to express by their use. All this will be rendered perfectly clear and distinct by means of the tables which are added to this work.

## C H A P VIII.

*Of the Radical Principle of Water, and of its  
Decomposition by Charcoal and Iron.*

UNTIL very lately, water has always been thought a simple substance; infomuch that the older chemists considered it as an element. Such it undoubtedly was to them, as they were unable to decompose it; or, at least, since the decomposition which took place daily before their eyes, was entirely unnoticed. But we mean to prove, that water is by no means a simple or elementary substance. I shall not here pretend to give the history of this recent, and hitherto contested discovery, which is detailed in the Memoirs of the Academy for 1781; but shall only bring forward the principal proofs of the decomposition, and composition of water; and I may venture to say, that these will be convincing to such as consider them impartially.

*Experiment First.*

Having fixed the glass tube EF, Pl. VII. Fig. 11. of from 8 to 12 lines diameter, across a

furnace, with a small inclination from E to F; lute the superior extremity E to the glass retort A, containing a determinate quantity of distilled water; and to the superior extremity F, lute the worm SS, fixed into the neck of the doubly tubulated bottle H; which last has the bent tube KK adapted to one of its openings, in such a manner as to convey such æriform fluids or gases as may be disengaged, during the experiment, into a proper apparatus for determining their quantity and nature.

To render the success of this experiment certain, it is necessary that the tube EF be made of well annealed and difficultly fusible glass, and that it be coated over with a lute composed of clay mixed with powdered stone ware; besides which, it must be supported about its middle by means of an iron bar passed through the furnace, lest it should soften and bend during the experiment. A tube of China-ware or porcelain, would answer better than one of glass for this experiment, were it not difficult to procure one so entirely free from pores as to prevent the passage of the air or vapours.

When things are thus arranged, a fire is lighted in the furnace EFCD, which is supported of such a strength as to keep the tube EF red hot, but not to make it melt; and, at the same time, such a fire is kept up in the furnace VVXX, as

to keep the water in the retort A continually boiling.

In proportion as the water, in the retort A, is evaporated, it fills the tube EF, and drives out the air contained through the tube KK. The aqueous gas formed by evaporation, is condensed by cooling in the worm SS, and falls, drop by drop, into the tubulated bottle H. Having continued this operation until all the water be evaporated from the retort, and having carefully emptied all the vessels employed, we find that a quantity of water has passed over into the bottle H, exactly equal to what was before contained in the retort A, without any disengagement of gas whatsoever: So that this experiment turns out to be a simple distillation; and the result would have been exactly the same, if the water had been run from one vessel into the other, without having undergone the intermediate incandescence, by passing through the red hot tube EF.

*Experiment Second.*

The apparatus being disposed, as in the former experiment; 38 grs. of charcoal, broken in to moderately small parts, and which has previously been exposed for a long time to a red heat in close vessels, are introduced into the tube

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EF: Every thing else is managed exactly as in the preceding experiment.

The water, contained in the retort A, is distilled, as in the former experiment, and, being condensed in the worm SS, falls into the bottle H. But, at the same time, a considerable quantity of gas is disengaged, which, escaping by the tube KK, is received in a convenient apparatus for that purpose. After the operation is finished, we find nothing but a few atoms of ashes remaining in the tube EF; the 28 *grs.* of charcoal having entirely disappeared.

When the disengaged gasses are carefully examined, they are found to weigh 113.7 *grs.*\*; these are of two kinds, viz. 144 cubical inches of carbonic acid gas, weighing 100 *grs.* and 380 cubical inches of a very light gas, weighing only 13.7 *grs.* This latter gas takes fire, when in contact with air, by the approach of a lighted body: and when the water, which has passed over into the bottle H, is carefully examined, it is found to have lost 85.7 *grs.* of its weight. Hence, in this experiment, 85.7 *grs.* of water, joined to 28 *grs.* of charcoal, have combined in such a way as to form 100 *grs.* of carbonic

\* In the latter part of this work will be found a particular account of the processes necessary for separating the different kinds of gasses, and for determining their quantities, and the particular natures of each.—T.



acid, and 13.7 grs. of a particular gas capable of being burnt.

I have already shewn, that 100 grs. of carbonic acid gas consist of 72 grs. of oxygen, combined with 28 grs. of carbon; hence the 28 grs. of charcoal, placed in the glass tube, have acquired 72 grs. of oxygen from the water: and it follows, that 85.7 grs. of water are composed of 72 grs. of oxygen combined with 13.7 grs. of a gas susceptible of combustion. We shall see presently, that this gas cannot possibly have been disengaged from the charcoal, and must consequently have been produced from the water.

I have suppressed some circumstances in the above account of this experiment, which would only have rendered it complicated, and made its results obscure to the reader. For instance, the inflammable gas dissolves a very small part of the carbon, by which means its own weight is somewhat augmented, and that of the carbonic gas is proportionally diminished. Although the alteration produced by this circumstance is very considerable, yet I have thought it necessary to determine its effects by a rigid calculation, and to report, as above, the results of the experiment in its simplified state, as if this circumstance had not happened. At any rate, should any doubts remain respecting the consequences I have drawn from this experi-

ment, they will be fully dissipated by the following experiments, which I am going to adduce in support of my opinion.

*Experiment Third.*

The apparatus being disposed exactly as in the former experiment, with this difference, that instead of the 28 grs. of charcoal, the tube EF is filled with 274 grs. of soft iron, in thin plates, rolled up spirally. The tube is made red hot by means of its furnace, and the water, in the retort A, is kept constantly boiling, till it be all evaporated, and has passed through the tube E, F, to be condensed in the bottle H.

No carbonic acid is disengaged in this experiment; instead of which we obtain 416 cubical inches, or 15 grs. of inflammable gas, thirteen times lighter\* than atmospheric air. By examining the water which has been distilled, it is found to have lost 100 grs. and the 274 grs of iron, confined in the tube, are found to have acquired 85 grs. additional weight, and

\* This I conceive to be a very improper expression. I understand the meaning of one substance being thirteen times heavier than another; but I do not understand how one can be thirteen times lighter. One thirteenth of the weight of the heavier would be the proper expression for implying the comparative gravity of the lighter body.—T.

its magnitude is considerably augmented. The iron is now hardly attractable by the magnet. It dissolves in acids without effervescence. In short, it is converted into a black oxyd, precisely similar to that produced by the combustion of iron in oxygen gas.

In this experiment we have a true *oxydation* of iron by means of water, exactly similar to that produced in air by the assistance of heat. One hundred grains of water having been decomposed, 85 *grs.* of oxygen have combined with the iron, so as to convert it into the state of black oxyd, and 15 *grs.* of a peculiar inflammable gas are disengaged. From all this it clearly follows, that water is composed of oxygen combined with the base of an inflammable gas, in the respective proportion of 85 parts, by weight, of the former, to 15 parts of the latter.

Thus water, besides the oxygen, which is one of its elements, as it is of many other substances, contains another element as its constituent base or radical: and for this proper principle or element we must find an appropriate term. None that we could think of, seemed better adapted than the word *hydrogen*, which signifies the *generative principle of water*, from *ὕδωρ aqua*, and *γενεμαί gig-*

*nor*\*. We call the combination of this element with caloric, *hydrogen gas*; and the term hydrogen † expresses the base of that gas, or the radical of water.

This experiment furnishes us with a new combustible body, or, in other words, a body which has so much affinity with oxygen as to draw it from its connection with caloric, and to decompose oxygen gas. This combustible body has itself so great an affinity with caloric, that, unless when engaged in a combination with some other body, it always subsists in the aëriform or gaseous state, in the usual temperature and pressure of our atmosphere. In this state of gas it is about  $\frac{1}{13}$  of the weight of an equal bulk of

\* This expression Hydrogen has been very severely criticised by some, who pretend that it signifies engendered by water, and not that which engenders water. I am not Grecian enough to settle the grammatical dispute: but the experiments related in this chapter prove, that when water is decomposed, hydrogen is produced, and that, when hydrogen is combined with oxygen, water is produced; hence we may say, with equal truth, that water is produced from hydrogen, or hydrogen is produced from water.—T.

† In a former note, it is mentioned that this element appears to be the base of muriatic acid, and that, if the discovery be authentic, it might more properly be named *muriogen*. In this case, what the older chemists named inflammable air, will become, in the new nomenclature, *muriogen gas*; and water will become a real *oxyd of muriogen*.—T.

atmospheric air. It is not absorbed by water, though it is capable of holding a small quantity of that fluid in solution : and it is incapable of being used for respiration, without producing instant death.

As the property of burning, which this gas possesses in common with all other combustible bodies, is merely the power of decomposing air, and carrying off its oxygen from the caloric with which it is combined, it is easily understood, that it cannot burn, unless in contact with air or oxygen gas. Hence, when we set fire to a bottle full of this gas, it burns gently, first at the neck of the bottle, and then in the inside of it, in proportion as the external air gets in. This combustion is slow and successive, and only takes place at the surface of contact between the two gases. It is quite different when the two gases are mixed before they are set on fire. If, for instance, after having introduced one part of oxygen gas into a narrow-mouthed bottle, we fill it up with two parts of hydrogen gas, and bring a lighted taper, or other burning body, to the mouth of the bottle, the combustion of the two gases takes place instantaneously with a violent explosion. This experiment ought only to be made in a bottle of very strong green glass, holding not more than a pint, and strongly wrapped round with twine ; otherwise the operator will be exposed to great

danger from the rupture of the bottle, of which the fragments will be thrown about with great force.

If all that has been related above, concerning the decomposition of water, be exactly conformable to truth—if, as I have endeavoured to prove, that substance be really composed of hydrogen, as its proper constituent element, combined with oxygen—it ought to follow, that, by reuniting these two elements together, we should recompose water: and that this actually happens, may be judged of by the following experiment.

*Experiment Fourth.*

I took a large crystal balloon, A, Pl. IV. fig. 5. holding about 30 pints, having a large opening to which was cemented the plate of copper B C, pierced with four holes, in which four tubes terminate. The first tube H h, is intended to be adapted to an air-pump, by which the balloon may be exhausted of its air. The second tube gg, communicates, by its extremity MM, with a reservoir of oxygen gas, from which the balloon is to be filled. The third tube d D d', communicates, by its extremity d NN, with a reservoir of hydrogen gas. The extremity d' of this tube terminates in a capillary opening, through which the hydrogen



gas contained in the reservoir is forced, with a moderate degree of quickness, by the pressure of one or two inches of water. The fourth tube contains a metallic wire GL, having a knob at its extremity L, intended for giving an electrical spark from L to d', on purpose to set fire to the hydrogen gas. This wire is moveable in the tube, that we may be able to separate the knob L from the extremity d' of the tube D d'. The three tubes, d D d' gg, and Hh, are all provided with stop-cocks.

That the hydrogen gas and oxygen gas may be as much as possible deprived of water, they are made to pass, in their way to the balloon A, through the tubes MM, NN, of about an inch diameter, and these are filled with salts, which, from their deliquescent nature, greedily attract the moisture of the air: such are the acetite of potash, and the muriat or nitrat of lime\*. These salts must only be reduced to a coarse powder, lest they run into lumps, and prevent the gasses from getting through their interstices.

We must be provided before hand with a sufficient quantity of oxygen gas, carefully pu-

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\* See the nature of these salts in the second part of this book—A.

rified from all admixture of carbonic acid, by long contact with a solution of potash\*.

We must likewise have a quantity of hydrogen gas, equal to twice the bulk of the oxygen gas, and contained in a separate reservoir. This must be carefully purified in the same manner by long contact with a solution of potash in water. The best way to obtain this gas free from mixture, is, by decomposing water with pure soft iron, as directed in Exp. 3. of this chapter.

Having adjusted every thing properly, as above directed, the tube H h is adapted to an air-pump, and the balloon A is exhausted of its air. We next admit the oxygen gas, so as to fill the balloon: and then, by means of pressure, as is before mentioned, force a small stream of hydrogen gas, through its tube D d', to which we immediately set fire, by an electrical spark. By means of the above-described apparatus, we can continue the mutual combustion of these two gases for a long time; as we have the power of supplying them, to the balloon, from their reservoirs, in proportion as they are con-

\* By potash is here meant, pure or caustic vegetable alkali, deprived of carbonic acid, by means of quicklime. In the general, we may observe here, that all the alkalies and earths must invariably be considered as in their pure or caustic state, unless otherwise expressed—T. The method of obtaining this pure alkali of potash will be given in the sequel.—A.

fumed. I have in another place\* given a minute description of the apparatus used in this experiment; and have explained the manner of ascertaining the quantities of the gasses consumed with the most scrupulous exactitude.

In proportion to the advancement of the combustion, there is a deposition of water upon the inner surface of the balloon or matrafs A. The water gradually increases in quantity; and, gathering into large drops, runs down to the bottom of the vessel. It is easy to ascertain the quantity of water collected, by weighing the balloon both before and after the experiment. Thus we have a twofold verification of our experiment, by ascertaining both the quantities of the gasses employed, and of the water formed by their combustion, these two quantities must be equal to each other. By an operation of this kind, Mr. Meusnier and I ascertained, that it required 85 parts, by weight, of oxygen, united to 15 parts of hydrogen, to compose one hundred parts of water. This experiment, which has not hitherto been published, was made in presence of a numerous committee from the Academy of Sciences. We exerted, on that occasion, the most scrupulous attention to accuracy; and have reason to be-

\* See the third part of this work — A.

lieve, that the above proportions cannot vary a two hundredth part from absolute truth.

From these experiments, both analytical and synthetic, we may now affirm, that we have ascertained, with as much certainty as is possible in physical or chemical subjects, that water is not a simple elementary substance, but is composed of two elements, oxygen and hydrogen; which elements, when existing separately, have so strong an affinity for caloric, as only to subsist under the form of gas in the common temperature and pressure of our atmosphere.

This decomposition and recomposition of water is perpetually operating before our eyes, in the temperature of the atmosphere, by means of compound elective attractions. We shall presently see, that the phenomena attendant upon vinous fermentation, putrefaction, and even vegetation, are produced, at least in a certain degree, by the decomposition of water. It is very extraordinary, that this fact should have hitherto been overlooked by natural philosophers and chemists. Indeed, it strongly proves, that, in chemistry, as in natural philosophy, it is extremely difficult to overcome prejudices imbibed in early education, and to search for truth in any other road, than the one which we have been accustomed to follow.

I shall finish this chapter with an account of an experiment, much less demonstrative indeed

than those already related, but which has appeared to make more impression than any other upon the minds of many. When 16 ounces of alkohol are burnt in an apparatus\* properly adapted for collecting all the water disengaged during the combustion, we obtain from 17 to 18 ounces of water. As no substance can furnish a product larger than its original bulk, it is evident that something must have united with the alkohol during its combustion: and I have already shewn that this must be oxygen. Thus alkohol contains hydrogen, which is one of the elements of water; and the atmospheric air contains oxygen, which is the other element necessary to the composition of water†. This experiment is a new proof, that water is a compound substance.

\* See an account of this apparatus in the third part of this work—A.

† A large quantity of carbonic acid gas is likewise disengaged during the combustion of alkohol; this proceeds from the combination of carbon, contained along with hydrogen in the composition of the alkohol, with oxygen during the combustion. This latter circumstance is explained at large in the after parts of this work.—T.

## CHAP. IX.

*Of the Quantities of Caloric disengaged during different species of Combustion.*

IT has been already mentioned, that when equal quantities of different bodies are burnt in the centre of a hollow sphere of ice, and are supplied with air, at the temperature of  $32^{\circ}$ , the quantities of ice melted from the inside of the sphere, become measures of the relative quantities of caloric disengaged during the several combustions. Mr. de la Place and I have given a description of the apparatus employed for this kind of experiment, in the memoirs of the Academy for 1780, p. 355: and a description and plate of the same apparatus will be found in the third part of this work. With this apparatus, phosphorus, charcoal, and hydrogen gas, gave the following results.

One pound of phosphorus melted 100 lbs.\* of ice.

\* In the original, the quantities resulting from the several experiments mentioned in this chapter, are given in pounds, ounces gros, and grains; but as the subject is curious and interesting, they are here reduced to decimals of the pound, by which they become equally useful to the British as to the French reader.—T.



One pound of charcoal melted 96.5 *lbs.*

One pound of hydrogen gas melted 295.5895 *lbs.*

As a concrete acid is formed by the combustion of phosphorus, it is probable, that very little caloric remains in the acid; and, consequently, that the above experiment gives us very nearly the whole quantity of caloric contained in the oxygen gas. Even if we suppose the phosphoric acid to contain a good deal of caloric, yet, as the phosphorus must have contained nearly an equal quantity before combustion, the error must be very small, as it will only consist of the difference between what was contained in the phosphorus before, and in the phosphoric acid after combustion.

I have already shown, in Chap. V. that one pound of phosphorus absorbs one pound eight ounces of oxygen during combustion: and, since, by the same operation, 100 *lbs.* of ice are melted, it follows, that the quantity of caloric contained in one pound of oxygen gas is capable of melting 66.6667 *lbs.* of ice.

One pound of charcoal during combustion melts only 96.5 *lbs.* of ice, while it absorbs 2.5714 *lbs.* of oxygen. By the experiment with phosphorus, this quantity of oxygen gas ought to disengage a quantity of caloric sufficient to melt 171.414 *lbs.* of ice: consequently, during this experiment, a quantity of caloric

sufficient to melt 74.914 *lbs.* of ice, disappears. Carbonic acid is not, like phosphoric acid, in a concrete state, after combustion, but in the state of gas; and requires to be united with caloric to enable it to subsist in that state: and the quantity of caloric, which is missing in the last experiment, is evidently employed for that purpose. When we divide that quantity by the weight of carbonic acid, formed by the combustion of one pound of charcoal, we find, that the quantity of caloric, necessary for changing one pound of carbonic acid from the concrete to the gaseous state, would be capable of melting 20.9766 *lbs.* of ice.

We may make a similar calculation with the combustion of hydrogen gas and the consequent formation of water. During the combustion of one pound of hydrogen gas, 5.6667 *lbs.* of oxygen gas are absorbed, and 295.5895 *lbs.* of ice are melted. But 5.6667 *lbs.* of oxygen gas, in changing from the æriform to the solid state, lose, according to the experiment with phosphorus, enough of caloric to have melted 377.7534 *lbs.* of ice. There is only disengaged, from the same quantity of oxygen, during its combustion with hydrogen gas, as much caloric as melts 295.1523 *lbs.*; wherefore there remains in the water at 32°, which is formed, during this experiment, as much caloric as would melt 82.6211 *lbs.* of ice.

Hence, as 6.6667 *lbs.* of water are formed, from the combustion of one pound of hydrogen gas, with 5.6667 *lbs.* of oxygen; it follows that, in each pound of water, at the temperature of  $32^{\circ}$ , there exists as much caloric as would melt 12.2708 *lbs.* of ice; without taking into account the quantity originally contained in the hydrogen gas, which we have been obliged to omit, for want of data to calculate its quantity\*. From this it appears, that water, even in the state of ice, contains a considera-

\* From the general principles of the new chemical philosophy, Hydrogen gas ought to contain a much larger quantity of caloric for giving it the gaseous state than oxygen gas. Being thirteen times as rare, it may be supposed to contain thirteen times as much caloric. Hence, if all the caloric of the two gases were disengaged during their combustion, and the consequent formation of water, 1244.4167 *lbs.* of ice should have been melted. But only 295.1522 *lbs.* are melted, and therefore, on this supposition, the remaining caloric, in 6.6667 *lbs.* of water, would be able to melt 94.92643 *lbs.* ice; or each pound of water, at the temperature of  $32^{\circ}$ , should contain as much caloric as is sufficient to melt 142 *lbs.* of ice nearly, which is absurd; for one pound of water, at  $32^{\circ}$ , must contain precisely as much caloric as is necessary to melt one pound of ice. This shows the fallacy of reasonings drawn from the supposable quantities of caloric in bodies; and that we are hitherto very far from possessing any accurate knowledge of that part of chemistry in which caloric is concerned.—T.

ble quantity of caloric, and that oxygen, in entering into the combination, retains likewise a good proportion.

From these experiments, we may assume the following results as sufficiently established.

*Combustion of Phosphorus.*

From the combustion of phosphorus, as related in the foregoing experiments, it appears, that one pound of phosphorus requires 1.5 lb. of oxygen gas for its combustion; and that 2.5 lbs. of concrete phosphoric acid are produced.

The quantity of caloric disengaged by the combustion of one pound of phosphorus, expressed by the number of pounds of ice melted during that operation, is 100.00000

The quantity disengaged from each pound of oxygen, during the combustion of phosphorus, expressed in the same manner; is 66.66667

The quantity disengaged during the formation of one pound of phosphoric acid, is 40.00000

The quantity remaining in each pound of phosphoric acid, is\* 0.00000

\* We here suppose the phosphoric acid not to contain any caloric, which is not strictly true; but, as I have before

*Combustion of Charcoal.*

In the combustion of one pound of charcoal, 2.5714 lbs. of oxygen gas are absorbed, and 3.5714 lbs. of carbonic acid gas are formed: Hence the

Caloric disengaged during the combustion of one pound of charcoal*	96.50000
Caloric disengaged during the combustion of charcoal, from each pound of oxygen gas absorbed,	37.52823
Caloric disengaged during the formation of one pound of carbonic acid gas,	27.02024
Caloric retained by each pound of oxygen after combustion,	29.13844
Caloric necessary for supporting one pound of carbonic acid in the state of gas,	20.97960

*Combustion of Hydrogen Gas.*

In the combustion of one pound of hydrogen gas, 5.6667 lbs. of oxygen gas are absorbed,

observed, the quantity it really contains is probably very small: and we have not given it a value, for want of sufficient data to go upon —A.

\* All these relative quantities of caloric are expressed by the number of pounds of ice, and decimal parts, melted during the several operations. —T.

and 6.6667 lbs. of water are formed : Hence the

Caloric disengaged from each lb. of hydrogen gas*,	295.58950
Caloric disengaged from each lb. of oxygen gas, -	52.16280
Caloric disengaged during the formation of each pound of water,	44.33840
Caloric retained by each lb. of oxygen after combustion with hydrogen, - - -	14.50386
Caloric retained by each lb. of water, at the temperature of 32°,	12.32823

*Of the Formation of Nitric Acid.*

When nitrous gas is combined with oxygen gas, so as to form nitric or nitrous acid, a degree of heat is produced, which is much less considerable than what is evolved during the other combinations of oxygen; whence it follows, that oxygen, when it becomes fixed in nitric acid, retains a great part of the heat

\* We are now told upon what data Mr. Lavoisier proceeds for ascertaining the quantity of caloric disengaged during the combustion of each pound of hydrogen gas. In a former note, I have supposed, that it might be thirteen times as much as that of water: hence it would be 623.1164, instead of the above number.—T.



which it possessed in the state of gas. It is certainly possible to determine the quantity of caloric which is disengaged during the combination of these two gasses, and consequently to determine what quantity remains after the combination takes place. The first of these quantities might be ascertained, by making the combination of the two gasses in an apparatus surrounded by ice. But, as the quantity of caloric disengaged is very inconsiderable, it would be necessary to operate upon a large quantity of the two gasses, and in a very troublesome and complicated apparatus. By this consideration, Mr de la Place and I have hitherto been prevented from making the attempt. In the mean time, the place of such an experiment may be supplied by calculations, the results of which cannot be very far from truth.

Mr de la Place and I deflagrated a convenient quantity of nitre and charcoal in an ice apparatus, and found that twelve pounds of ice were melted by the deflagration of one pound of nitre. We shall see, in the sequel, that one pound of nitre is composed, as under, of

Potash	7 oz.	6 gros.	51.84 grs.	=	4515.84 grs.
Dry acid	8	1	21.16	=	4700.16.

The above quantity of dry acid is composed of,

Oxygen	6 oz.	3 gros	66.34 grs.	=	3738.34 grs.
Azot	1	5	25.82	=	961.82

By this we find that, during the above deflagration,  $145\frac{1}{3}$  grs. of carbon\* have suffered combustion, along with 3738.34 grs. or 6 oz. 3 gros 66.34 grs. of oxygen. Hence, since 12 lbs. of ice were melted during the combustion, it follows, that one pound of oxygen, burnt in the same manner, would have melted 29.5832 lbs. of ice. To which if we add the quantity of caloric retained by a pound of oxygen, after combining with carbon to form carbonic acid gas, which was already ascertained to be capable of melting 29.13844 lbs. of ice, we shall have for the total quantity of caloric remaining in a pound of oxygen, when combined with nitrous gas in the nitric acid, 58.72164; which is the number of pounds of ice the caloric remaining in the oxygen in that state is capable of melting.

We have before seen, that, in the state of oxygen gas, it contained at least 66.66667; wherefore it follows that, in combining with azot to form nitric acid, it only loses 7.94502. Farther

\* From this it appears, that the proportions used by Mr Lavoisier were 1 lb. or 9216 grs. of nitrate to 2 gros  $1\frac{1}{3}$  grs. or 145.24 grs. of charcoal, though he has not chosen to mention it in direct terms — T.

experiments upon this subject are necessary to ascertain how far the results of this calculation may agree with direct fact. This enormous quantity of caloric, retained by oxygen in its combination into nitric acid, explains the cause of the great disengagement of caloric during the deflagrations of nitre : or, more strictly speaking, upon all occasions of the decomposition of nitric acid.

*Of the Combustion of Wax.*

Having examined several cases of simple combustion, I mean now to give a few examples of a more complex nature. One pound of wax-taper being allowed to burn slowly in an ice apparatus, melted 133.1667 *lbs.* of ice. According to my experiments, as given in the memoirs of the Academy for 1784, p. 606, one pound of wax-taper consists of 0.8228 *lbs.* of carbon, and 0.1772 *lbs.* of hydrogen.

By the foregoing experiments, the above quantity of carbon ought to melt, 79.39390 *lbs.* of ice;

And the hydrogen

should melt

52.37605

---

In all 131.76995 *lbs.*

Thus, we see that the quantity of caloric disengaged from a burning taper, is nearly conformable to what was obtained by burning separately a quantity of carbon and hydrogen equal to what enters into its composition. These experiments with the taper were several times repeated, so that I have reason to believe them accurate.

*Combustion of Olive Oil.*

We included a burning lamp, containing a determinate quantity of olive oil, in the ordinary apparatus; and, when the experiment was finished, we ascertained exactly the quantities of oil consumed, and of ice melted; the result was, that, during the combustion of one pound of olive oil, 148.8828 *lbs.* of ice were melted. By my experiments, in the Memoirs of the Academy for 1784, and of which the following chapter contains an abstract, it appears that one pound of olive oil consists of 0.7896 *lbs.* of carbon, and 0.2104 *lbs.* of hydrogen. By the foregoing experiments, that quantity of carbon should melt 76.18723 *lbs.* of ice: and the quantity of hydrogen, in a pound of the oil, should melt 62.15053 *lbs.* The sum of these two gives 138.33776 *lbs.* of ice, which the two constituent elements of the oil would have melted, had they separately suffered com-

buftion: whereas the oil had really melted 143.88330 lbs. which gives an excefs of 10.54544 in the refult of the experiment, above the calculated refult, from data furnifhed by former experiments.

This difference, which is by no means very confiderable, may arife from errors which are unavoidable in experiments of this nature, or it may be owing to the compofition of oil not being as yet exactly afcertained. It proves, however, that there is a great agreement between the refults of our experiments, refpecting the combination of caloric, and thofe which regard its difengagement.

The following defiderata ftill remain to be determined; viz. What quantity of caloric is retained by oxygen, after combining with metals to convert them into oxyds? What quantity is contained by hydrogen, in its different ftates of exiftence? and, To afcertain, with more precision than is hitherto attained, how much caloric is difengaged during the formation of water; as there ftill remain confiderable doubts with refpect to our prefent determination of this point, which can only be removed by farther experiments. We are at prefent occupied with this inquiry: and, when thefe feveral points are well afcertained, which we hope they will foon be, we fhall probably be under the neceffity of making confiderable corrections upon

most of the results of the experiments and calculations in this chapter. I did not, however, consider this as a sufficient reason for withholding so much as is already known, from such as may be inclined to labour upon the same subject. It is difficult, in our endeavours to discover the principles of a new science, to avoid beginning by conjecture: and it is rarely possible to attain perfection at the first setting out.



## C H A P. X.

*Of the Combinations of Combustible Substances with each other.*

AS combustible substances in general have a great affinity for oxygen, they ought likewise to attract, or tend to combine with, each other; *Quæ sunt eadem uni tertio, sunt eadem inter se*; and the axiom is found to be true. Almost all the metals, for instance, are capable of uniting with each other, and of forming what are called *alloys*\* in common language. Most of these, like other chemical combinations, are susceptible of several degrees of saturation. The greater number of alloys are more brittle than the pure metals of which they are composed, especially when the metals alloyed together are considerably different in

\* This term *alloy*, which we have from the language of the arts, serves exceedingly well for distinguishing all the combinations or intimate unions of metals with each other, and is adopted in our new nomenclature for that purpose—A.

their degrees of fusibility. To this difference in fusibility, part of the phenomena attendant upon *alloyage* are owing; particularly that property of iron, called by workmen *hotshort*. This kind of iron must be considered as an alloy, or mixture of pure iron, which is almost infusible, with a small portion of some other metal, which fuses in a much lower degree of heat: So long as this alloy remains cold, and both metals are in the solid state, the mixture is malleable; but when heated to a sufficient degree to liquefy the more fusible metal, the particles of this liquid metal, which are interposed between the particles of the solid iron, must destroy their continuity, and occasion the alloy to become brittle. The alloys of mercury, with the other metals, have usually been called *amalgams*: and we see no inconvenience from continuing the use of that term.

Sulphur, phosphorus, and carbon, readily unite with metals. Combinations of sulphur with metals are usually named *pyrites*. Their combinations with phosphorus and carbon are either not yet named, or have received new names only of late: wherefore we have not scrupled to change them according to our principles. The combinations of metal and sulphur we call *sulphurets*; those formed with phosphorus *phosphurets*, and those with carbon

*carburets*\*. These denominations are extended to all the combinations into which the above three substances enter, without being previously oxygenated. Thus, the combination of sulphur with potash, or fixed vegetable alkali, is called *sulphuret of potash*; that which it forms with ammoniac, or volatile alkali, is termed *sulphuret of ammoniac*.

Hydrogen is likewise capable of combining with many combustible substances. In the state of gas, it dissolves carbon, sulphur, phosphorus, and several metals. We distinguish these combinations by the terms, *carbonated hydrogen gas*, *sulphurated hydrogen gas*, and *phosphorated hydrogen gas*. The sulphurated hydrogen gas was called *hepatic air* by former chemists; or *fetid air from sulphur*, by Mr Scheele. The virtues of several mineral waters, and the foetid smell of animal excrements, chiefly arise from the presence of this gas. The phosphorated hydrogen gas is remarkable for the property, discovered

\* In the French nomenclature, these compounds are named *sulphures*, *phosphures*, and *carbures*; but though these terms may be sufficiently distinguishable from *soufre*, *phosphore*, and *carbone*, they are not, especially the two first, distinct enough in English. I have therefore chosen to borrow the new English terms in the text, from the Latin edition of the new nomenclature, where they are called respectively *sulphurettum*, *phosphorettum*, and *carburettum* — T.

by Mr Gengembre, of taking fire spontaneously upon getting into contact with atmospheric air, or, what answers better, with oxygen gas: This gas has a strong flavour, resembling that of putrid fish: and it is very probable that the phosphorescent quality of fish, in the state of putrefaction, arises from the escape of this species of gas. When hydrogen and carbon are combined together, without the intervention of caloric to bring the hydrogen into the state of gas, they form oil, which is either fixed or volatile, according to the proportions of hydrogen and carbon in its composition\*. The chief difference between fixed or fat oils drawn from vegetables by expression, and volatile or essential oils, is, that the former contains an excess of carbon, which is separated when the oils are heated above the degree of boiling water; whereas the volatile oils, containing a just proportion of these two constituent ingredients, are not liable to be decomposed by that heat, but, uniting with caloric into the gaseous state, pass over in distillation unchanged.

\* We shall afterwards see, that oil contains oxygen, combined with the abovementioned ingredients, and that it is a hydrocarbonous or carbonohydrous oxyd; hence the difference between the various kinds may in part be owing to their different degrees of oxydation, as well as to the proportions of the other ingredients.—T.

In the Memoirs of the Academy for 1784, p. 593, I gave an account of my experiments upon the composition of oil and alkohol, by the union of hydrogen with carbon, and of their combination with oxygen. By these experiments, it appears, that fixed oils combine with oxygen during combustion, and are thereby converted into water and carbonic acid. By means of calculation, applied to the products of these experiments, we find that fixed oil is composed of 21 parts, by weight, of hydrogen, combined with 79 parts of carbon. Perhaps the solid substances of an oily nature, such as wax, contain a proportion of oxygen, to which they owe their state of solidity. I am at present engaged in a series of experiments, which, I hope, will throw great light on this subject.

It is worthy of being examined, whether hydrogen in its concrete state, uncombined with caloric, be susceptible of combination with sulphur, phosphorus, and the metals. There is nothing that we know of, which, *a priori*, should render these combinations impossible; for combustible bodies being in general susceptible of combination with each other, there is no evident reason for hydrogen being an exception to the rule. However, no direct experiment as yet establishes either the possibility or impossibility of this union. Iron and

zinc are the most likely, of all the metals, for entering into combination with hydrogen. But, as these have the property of decomposing water, and as it is very difficult to get entirely free from moisture in chemical experiments, it is hardly possible to determine whether the small portions of hydrogen gas, obtained in certain experiments with these metals, were previously combined with the metal in the state of solid hydrogen, or if they were produced by the decomposition of a minute quantity of water. The more care we take to prevent the presence of water in these experiments, the less is the quantity of hydrogen gas procured; and when very accurate precautions are employed, even that quantity becomes hardly sensible.

However this inquiry may turn out, respecting the power of combustible bodies, as sulphur, phosphorus, and metals, to absorb hydrogen, we are certain that they only absorb a very small portion: and that this combination, instead of being essential to their constitution, can only be considered as a foreign substance, which contaminates their purity. It is the province of the advocates\* for this system, to

\* By this I mean those supporters of the phlogistic theory, who consider hydrogen, or the base of inflammable air, as the phlogiston of the celebrated Stahl.—T.



prove by decisive experiments, the real existence of this combined hydrogen, which they have hitherto only done by conjectures founded upon suppositions.

Y

## C H A P   X I.

*Observations upon Oxyds and Acids with compound Bases—and on the Composition of Animal and Vegetable substances.*

WE have, in Chap V. and VIII. examined the products resulting from the combustion of the four simple combustible substances, sulphur, phosphorus, carbon, and hydrogen. We have shewn, in Chap. X. that the simple combustible substances are capable of combining with each other into compound combustible substances; and have observed, that oils in general, and particularly the fixed vegetable oils, belong to this class, being composed of hydrogen and carbon. It remains, in this chapter, to treat of the oxygenation of these compound combustible substances, and to show, that there exist acids and oxyds having double and triple bases. Nature furnishes us with numerous examples of this kind of combinations, by means of which, chiefly, she is enabled to produce a vast variety of compounds, from a very limited number of elements, or simple substances.

It was long ago well known, that, when muriatic and nitric acids were mixed together, a compound acid was formed, having properties quite distinct from those of either of the acids taken separately. This acid was called *aqua regia*, from its most celebrated property of dissolving gold, called *king of metals* by the alchemists. Mr Berthollet has distinctly proved, that the peculiar properties of this acid arise from the combined action of its two acidifiable bases: and, for this reason, we have judged it necessary to distinguish it by an appropriate name: that of *nitro-muriatic* acid appears extremely applicable, from its expressing the nature of the two substances which enter into its composition.

This phenomenon, of a double base in one acid, which had formerly been observed only in the nitro-muriatic acid, occurs continually in the vegetable kingdom; in which a simple acid, or one possessed of a single acidifiable base, is very rarely found. Almost all the acids procurable from this kingdom, have bases composed of carbon and hydrogen, or of carbon, hydrogen, and phosphorus, combined with more or less oxygen. All these bases, whether double or triple, are likewise formed into oxyds, having less oxygen than is necessary to give them the properties of acids. The acids and oxyds from the animal kingdom, are still more compound, as their bases generally consist of a

combination of carbon, phosphorus, hydrogen, and azot.

As it is but of late that I have acquired any clear and distinct notions of these substances, I shall not, in this place, enlarge much upon the subject, which I mean to treat of very fully in some memoirs I am preparing to lay before the Academy. Most of my experiments are already performed. But, to be able to give exact reports of the resulting quantities, it is necessary that they be carefully repeated, and increased in number: wherefore, I shall only give a short enumeration of the vegetable and animal acids and oxyds, and terminate this article by a few reflections upon the composition of vegetable and animal bodies.

Sugar, mucus, under which term we include the different kinds of gums, and starch, are vegetable oxyds, having hydrogen and carbon combined, in different proportions, as their radicals or bases, and united with oxygen, so as to bring them to the state of oxyds. From this state of oxyds, they are capable of being changed into acids, by the addition of a fresh quantity of oxygen: and, according to the degrees of oxygenation, and the proportion of hydrogen and carbon in their bases, they form the several kinds of vegetable acids.

It would be easy to apply the principles of our nomenclature to give names to these vege-

table acids and oxyds, by using the names of the two substances which compose their bases : They would thus become hydro-carbonous acids and oxyds. In this way we might indicate which of their elements existed in excess, without circumlocution, after the manner used by Mr Rouelle for naming the vegetable extracts : He calls these extracto-resinous, when the extractive matter prevails in their composition, and resino-extractive, when they contain a larger proportion of resinous matter. Following that plan, and by varying the terminations according to the formerly established rules of our nomenclature, we have the following denominations : Hydro-carbonous, hydro-carbonic, carbonohydrous, and carbonohydric, oxyds. And, for the acids : Hydro-carbonous, hydro-carbonic, oxygenated hydro-carbonic : carbonohydrous, carbonohydric, and oxygenated carbonohydric.

It is probable, that the above terms would suffice for indicating all the varieties in nature, and that, in proportion as the vegetable acids become well understood, they will naturally arrange themselves under these denominations. But, though we know the elements of which these are composed, we are as yet ignorant of the proportions of these ingredients, and are still far from being able to class them in the above methodical manner ; wherefore, we have de-

terminated to retain the old names provisionally. I am somewhat farther advanced in this inquiry than at the time of publishing our conjunct essay upon chemical nomenclature: yet it would be improper to draw decided consequences from experiments not yet sufficiently precise. Though I acknowledge that this part of chemistry still remains in some degree obscure, I must express my expectations of its being very soon elucidated.

I am still more forcibly necessitated to follow the same plan in naming the acids, which have three or four elements combined in their bases. Of these we have a considerable number from the animal kingdom, and some even from vegetable substances. Azot, for instance, joined to hydrogen and carbon, form the base or radical of the Prussic acid. We have reason to believe that the same happens with the base of Gallic acid; and almost all the animal acids have their bases composed of azot, phosphorus, hydrogen, and carbon. Were we to endeavour to express at once all these four component parts of the bases, our nomenclature would undoubtedly be methodical. It would have the property of being clear and determinate. But this assemblage of Greek and Latin substantives and adjectives, which are not yet universally admitted by chemists, would have the appearance of a barbarous language, difficult both to



pronounce and to be remembered. Besides, this part of chemistry being still far from that accuracy it must soon attain, the perfection of the science ought certainly to precede that of its language; and we must still, for some time, retain the old names for the animal oxyds and acids. We have only ventured to make a few slight modifications of these names, by changing the termination into *ous*, when we have reason to suppose the base to be in excess, and into *ic*, when we suspect that oxygen predominates.

The following are all the vegetable acids hitherto known :

- |                         |                       |
|-------------------------|-----------------------|
| 1. Acetous acid.        | 8. Pyro-mucous acid.  |
| 2. Acetic acid.         | 9. Pyro-lignous acid. |
| 3. Oxalic acid.         | 10. Gallic acid.      |
| 4. Tartarous acid.      | 11. Benzoic acid.     |
| 5. Pyro-tartarous acid. | 12. Camphoric acid.   |
| 6. Citric acid.         | 13. Succinic acid.    |
| 7. Malic acid.          |                       |

Though all these acids, as has been already said, are chiefly, and almost entirely, composed of hydrogen, carbon, and oxygen; yet, properly speaking, they contain neither water, carbonic acid, nor oil, but only the elements necessary for forming these substances. The power of affinity reciprocally exerted by the hydrogen, carbon, and oxygen, in these acids, is in a state

of equilibrium, which is only capable of existing in the ordinary temperature of the atmosphere. For, when they are heated but a very little above the temperature of boiling water, this equilibrium is destroyed; part of the oxygen and hydrogen unite, and form water; part of the carbon and hydrogen combine into oil; part of the carbon and oxygen unite to form carbonic acid; and, lastly, there generally remains a small portion of carbon, which, being in excess with respect to the other ingredients, is left free. I mean to explain this subject somewhat further in the succeeding chapter.

The oxyds of the animal kingdom are hitherto less known than those from the vegetable kingdom; and their number as yet is not at all determined. The red part of the blood, lymph, and most of the secretions, are true oxyds, under which point of view it is very important to consider them. We are only acquainted with six animal acids, several of which, it is probable, approach very near each other in their nature, or, at least, differ only in a scarcely sensible degree. I do not include the phosphoric acid amongst these, because it is found in all the kingdoms of nature. They are,

- |                        |                  |
|------------------------|------------------|
| 1. Lactic acid.        | 4. Formic acid.  |
| 2. Saccho-lactic acid. | 5. Sebacic acid. |
| 3. Bombic acid.        | 6. Prussic acid. |

The connection between the constituent elements of the animal oxyds and acids is not more permanent than in those from the vegetable kingdom; as a small increase of temperature is sufficient to overturn the equilibrium. I hope to render this subject more distinct in the following chapter than has been done hitherto.

## C H A P. XII.

*Of the Decomposition of Vegetable and Animal Substances by the Action of Fire.*

**B**EFORE we can thoroughly comprehend what takes place during the decomposition of vegetable substances by fire, we must take into consideration the nature of the elements which enter into their composition, and the different affinities which the particles of these elements exert upon each other, and the affinity which caloric possesses with each of them. The true constituent elements of vegetables are hydrogen, oxygen, and carbon. These are common to all vegetables; and no vegetable can exist without them. Such other substances as exist in particular vegetables, are only essential to the composition of those in which they are found; and do not belong to vegetables in general.

Of these elements, hydrogen and oxygen have a strong tendency to unite with caloric, and be converted into gas; while carbon is a fixed element, having little affinity with caloric. On the other hand, oxygen, which, in the usual temperature, tends almost equally to unite

with hydrogen or with carbon, has a much stronger affinity with carbon, when at the red heat\*, and then unites with it to form carbonic acid.

Although we are far from being able to appreciate all these powers of affinity, or to express their proportional energy by numbers, we are certain, that, however variable they may be, when considered in relation to the quantity of caloric with which they are combined, they are all nearly in equilibrium in the usual temperature of the atmosphere. Hence vegetables neither contain oil†, water, nor carbonic acid, though they contain all the elements of these substances. The hydrogen is not combined particularly with the oxygen, nor with the car-

\* Though this term, red heat, does not indicate any absolutely determinate degree of temperature, I shall use it sometimes to express a temperature considerably above that of boiling water.—A.

† I must be understood here to speak of vegetables reduced to a perfectly dry state ; and, with respect to oil, I do not mean that which is procured by expression either in the cold, or in a temperature not exceeding that of boiling water. I only allude to the empyreumatic oil, procured by distillation with a naked fire, in heat superior to the temperature of boiling water ; which is the only oil declared to be produced by the operation of fire. What I have published upon this subject, in the Memoirs of the Academy for 1786, may be consulted.— A.

bon ; and, reciprocally, the particles of these three substances form a triple combination, which remains in equilibrium, while undisturbed by caloric ; but a very slight increase of temperature is sufficient to overturn this structure of combination.

If the increased temperature, to which the vegetable is exposed, does not exceed the heat of boiling water, one part of the hydrogen combines with the oxygen, and forms water ; the rest of the hydrogen combines with a part of the carbon, and forms volatile oil ; while the remainder of the carbon, being set free from its combination with the other elements\*, remains fixed in the bottom of the distilling vessel.

When, on the contrary, we employ a red heat, no water is formed ; or, at least, any that may have been produced, by the first application of the heat, is decomposed ; the oxygen, having a greater affinity with the carbon at this degree of heat, combines with it to form carbonic acid ; and the hydrogen, being left free from combination with the other elements, unites with caloric, and escapes in the state of

\* This statement is only partially true ; for a small part of the ingredients remains very obstinately attached to the carbon, and can hardly be driven from it without the assistance of oxygen, by means of which the carbon itself suffers combustion.—T.



hydrogen gas\*. In this high temperature, either no oil is formed, or if any has been produced during the lower temperature, at the beginning of the experiment, it is decomposed by the action of the red heat. Thus the decomposition of vegetable matter, under a high temperature, is produced by the action of double and triple affinities; while the carbon attracts the oxygen, on purpose to form carbonic acid, the caloric attracts the hydrogen, and converts it into hydrogen gas.

The distillation of every species of vegetable substance confirms the truth of this theory, if we can give that name to a simple relation of facts. When sugar is submitted to distillation, so long as we only employ a heat but a little below that of boiling water, it only loses its water of crystallization; it still remains sugar, and retains all its properties. But, immediately upon raising the heat only a little above that degree, it becomes blackened; a part of the carbon separates from the combination; water slightly acidulated passes over, accompanied by

\* The hydrogen gas, produced in this way, is not pure, but holds a considerable portion of carbon in solution. It is carbonated hydrogen gas, called in the old chemical language, heavy inflammable air.—T.

a little oil; and the charcoal\*, which remains in the retort, is nearly a third part of the original weight of the sugar.

The operation of affinities which takes place, during the decomposition, by fire, of vegetables which contain azot, such as the cruciferous plants, and of those containing phosphorus, is more complicated. But, as these substances only enter into the composition of vegetables in very small quantities, they only, apparently, produce slight changes upon the products of distillation. The phosphorus seems to combine with carbon; and, acquiring fixity from that union, remains behind in the retort; while the azot, combining with a part of the hydrogen, forms ammoniac†, or volatile alkali.

Animal substances, being composed nearly of the same elements with cruciferous plants,

\* The term charcoal is here retained, because it is still contaminated with several foreign matters. Carbon, strictly speaking, is only used to denominate the pure elementary and combustible part of charcoal, which part acts alone in combinations and decompositions.—T.

† Dr Black's proposed term, *ammonia*, as will be more particularly noticed in the sequel, seems better adapted, as a single term for this substance, than the one here used. Besides, in the above explanation, the ammoniac or ammonia, whichever term be preferred, is not pure, being combined with carbonic acid; wherefore it ought to have been named carbonated ammoniac.—T.

give almost the same products in distillation; with this difference, that, as they contain a greater quantity of hydrogen and azot, they produce more oil and more ammoniac. I shall only produce one fact as a proof of the exactness with which this theory explains all the phenomena that occur during the distillation of animal substances; which is the rectification, and total decomposition, of volatile animal oil, commonly known by the name of Dippels' oil. When these oils are procured by a first distillation, in a naked fire, they are brown, from containing a little carbon, almost in a free state. But they become quite colourless by rectification. Even in this state, the carbon in their composition has so slight a connection with the other elements, as to separate from them by mere exposure to the air. If we put a quantity of this animal oil, well rectified, and consequently clear, limpid, and transparent, into a bell-glass filled with oxygen gas over mercury, in a short time the gas is much diminished, being absorbed by the oil. The oxygen, combining with the hydrogen of the oil, forms water, which sinks to the bottom. At the same time the carbon, which was combined with the hydrogen, being set free, manifests itself by rendering the oil black. Hence the only way of preserving these oils colourless and transparent, is by keeping them in bottles perfectly full, and accurate-

ly corked, to hinder the contact of air, which always discolours them.

Successive rectifications of this oil furnish another phenomenon confirming our theory. In each distillation a small quantity of charcoal remains in the retort; and a little water is formed, by the union of the oxygen contained in the air of the distilling vessels with the hydrogen of the oil. As this takes place in each successive distillation, if we make use of large vessels and a considerable degree of heat, we at last decompose the whole of the oil, and change it entirely into water and charcoal. When we use small vessels, and especially when we employ a slow fire, or a degree of heat only a little above that of boiling water, the total decomposition of these oils, by repeated distillation, is greatly more tedious, and more difficultly accomplished. I shall give a particular detail to the academy, in a separate memoir, of all my experiments upon the decomposition of oil. But what I have related above may suffice to give just general ideas of the composition of animal and vegetable substances, and of their decomposition by the action of fire.

## C H A P. XIII.

*Of the Decomposition of Vegetable Oxyds by the  
Vinous Fermentation.*

THE manner in which wine, cyder, mead, and all the liquors formed by the spiritous fermentation, are produced, is well known to every one. The juice of grapes or of apples being expressed, and the latter being diluted with water, they are put into large vats, which are kept in a temperature of at least  $54.5^{\circ}$  of the thermometer. A rapid intestine motion, or fermentation, very soon takes place; numerous globules form in the liquid, and burst at the surface. When the fermentation is at its height, the quantity of gas disengaged is so great, as to make the liquor appear as if boiling violently over a fire. When this gas is carefully gathered, it is found to be carbonic acid perfectly pure\*, and free from admixture with any other species of air or gas.

\* This assertion of the perfect purity of carbonic acid gas, disengaged during the vinous fermentation, must be taken with some allowance; for it almost always, I believe constant.

When the fermentation is completed, the juice of grapes is changed, from being sweet and full of sugar, into a vinous liquor, which no longer contains any sugar, and from which we procure, by distillation, an inflammable liquor, known in commerce under the name of Spirit of Wine. As this liquor is produced by the fermentation of any saccharine matter whatever, diluted with water, it must have been contrary to the principles of our nomenclature to call it spirit of wine, rather than spirit of cyder, or of fermented sugar. Wherefore, we have adopted a more general term, and the Arabic word *alkohol* seems extremely proper for the purpose.

This operation is one of the most extraordinary in chemistry. We must examine whence proceed the disengaged carbonic acid and the inflammable liquor produced, and in what manner a sweet vegetable oxyd becomes thus converted into two such opposite substances, whereof one is combustible, and the other eminently the contrary. To solve these two questions, it is necessary to be previously acquainted with the analysis of the fermentable substance, and of the products of the fermentation.

ly, contains some alkohol, besides a considerable quantity of aqueous gas or water, in solution. The latter does not affect its purity ; the former does so in some degree.—T.



We may lay it down, as an incontestible axiom, that, in all the operations of art and nature, nothing is created. An equal quantity of matter exists both before and after the experiment; the quality and quantity of the elements remain precisely the same: and nothing takes place beyond changes and modifications in the combinations of these elements. Upon this principle, the whole art of performing chemical experiments depends. We must always suppose an exact equality between the elements of the body examined, and those of the products of its analysis.

Hence, since from must of grapes we procure alcohol and carbonic acid, I have undoubted right to suppose that must consists of carbonic acid and alcohol\*. From these premises, we have two methods of ascertaining what passes during vinous fermentation: Either by determining the nature of, and the elements which compose, the fermentable substances; or by accurately examining the products resulting from fermentation. And it is evident, that the know-

\* In this assertion, the consequences do not strictly follow from the premises; because, from the must of grapes we procure carbonic acid and alcohol, it is a necessary consequence that the original must contains the constituent elements of carbonic acid and of alcohol, but not that these products of fermentation are already formed.—T.

ledge of either of these must lead to accurate conclusions concerning the nature and composition of the other. From these considerations, it became necessary accurately to determine the constituent elements of the fermentable substances: and, for this purpose, I did not make use of the compound juices of fruits, the rigorous analysis of which is perhaps impossible; but made choice of sugar, which is easily analysed, and the nature of which I have already explained. This substance is a true vegetable oxyd with two bases, composed of hydrogen and carbon, brought to the state of an oxyd, by means of a certain proportion of oxygen; and these three elements are combined in such a way, that a very slight force is sufficient to destroy the equilibrium of their connection. By a long train of experiments, made in various ways, and often repeated, I ascertained, that the proportions, in which these ingredients exist in sugar, are nearly 8 parts of hydrogen, 64 parts of oxygen, and 28 parts of carbon, all by weight, forming 100 parts of sugar.

Sugar must be mixed with about four times its weight of water, to render it susceptible of fermentation: and even then the equilibrium of its elements would remain undisturbed, without the assistance of some substance to give a commencement to the fer-

mentation\*. This is accomplished by means of a little yeast from beer : and, when the fermentation is once excited, it continues of itself until completed. I shall, in another place, give an account of the effects of yeast, and other ferments, upon fermentable substances. I have usually employed 10 *lbs.* of yeast, in the state of paste, for each 100 *lbs.* of sugar, with as much water as is four times the weight of the sugar. I shall give the results of my experiments exactly as they were obtained, preserving even the fractions produced by calculation.

\* This is not strictly true ; for, especially in warm weathers, all syrups are apt to run into fermentation, unless very rich of the sugar, and carefully preserved. At the same time, this spontaneous fermentation is not so regular as when assisted by yeast, and is apt to become in part acetous, before completing the vinous process.—T.

TABLE I. *Materials of Fermentation\*.*

Water	-	-	lbs.
Sugar	-	-	400.
Yeast, in paste, 10 lbs.	-	-	100.
composed of	{	Water	-
	{	Dry Yeast	-
			7.2391493
			2.7608507
<hr/>			
Total 510. lbs.			

TABLE II. *Constituent Elements of the Materials of Fermentation.*

407.2391493 lbs. of water, composed of	{	Hydrogen	lbs
	{	Oxygen	61.0858724
			346.1532769
100 lbs. sugar, composed of	{	Hydrogen	8.
	{	Oxygen	64.
	{	Carbon	28.
2.7608507 lbs. of dry yeast, composed of	{	Hydrogen	.2900716
	{	Oxygen	1.6437457
	{	Carbon	.7876519
	{	Azot	.0393815
<hr/>			
Total weight 510. lbs.			

\* The quantities in the original are expressed in the common divisions of the Paris pound: but, to render the results more generally useful to the English reader, they are all here reduced to decimals, which answer equally for any pound.—T.

TABLE III. *Recapitulation of these Elements.*

Oxygen	{	of the water	lbs.	{	lbs.
		of the water	340.		
		in the yeast	6.1532769		
		of the sugar	64.		
		of the dry yeast	1.6437457		411.7970226
Hydrogen	{	of the water	60.	{	69.3759440
		of the water	1.0858724		
		in the yeast	8.		
		of the sugar	0.2900716		
		of the dry yeast			
Car- bon	{	of the sugar	28.	{	28.7876519
		of the yeast	0.7876519		
Azot of the yeast			.		0.0393815
					<hr/>
In all 510. lbs.					

Having thus accurately determined the nature and quantity of the constituent elements of the materials submitted to fermentation, we have next to examine the products resulting from that process. For this purpose, I placed the above 510 lbs. of fermentable liquor in a proper\* apparatus, by means of which I could accurately determine the quantity and quality of gas disengaged during the fermentation, and

\* The above apparatus is described in the Third Part.—A.

could even weigh every one of the products separately at any period of the process I judged proper.

An hour or two after the substances are mixed together, especially if they be kept in a temperature of from  $66^{\circ}$  to  $73^{\circ}$  of the thermometer, the first marks of fermentation commence. The liquor turns thick and frothy; little globules of air are disengaged, which rise and burst at the surface; the quantity of these globules quickly increases; and there is a rapid and abundant production of very pure carbonic acid, accompanied with a scum, which is the yeast separating from the mixture. After some days, less or more according to the degree of heat, the intestine motion and disengagement of gas diminish. But these do not cease entirely; nor is the fermentation completed for a considerable time. During the process, 35.3458116 *lbs.* of dry carbonic acid are disengaged, which carry along with them 13.9140625 *lbs.* of water. There remain in the vessel 460.7401259 *lbs.* of vinous liquor, slightly acidulous. This is at first muddy, but clears of itself, and deposits a portion of yeast. When we separately analyse all these substances, which is effected by very troublesome processes, we have the results as given in the following Tables. This process, with all the subordinate calculations and analyses, will be detailed at large in the Memoirs of the Academy.



TABLE IV. *Products of Fermentation.*

35.3458116	lbs. of carbonic acid, composed of	{	Oxygen	-	25.4490017
		{	Carbon	-	9.8968099
408.9780816	lbs. of water, composed of	{	Oxygen	-	347.6314019
		{	Hydrogen	-	61.3466797
57.7016059	lbs. of dry alcohol, composed of	{	Oxygen, combined with hydrogen		31.3897570
		{	Hydrogen, combined with oxygen		5.5393880
		{	Hydrogen, combined with carbon		4.0390625
		{	Carbon, combined with hydrogen		16.7333984
2 5000000	lbs of dry acetic acid, composed of	{	Hydrogen	-	0.1562500
		{	Oxygen	-	1.7187500
		{	Carbon	-	0.6250000
4.0940755	lbs. of residuum of sugar, composed of	{	Hydrogen	-	0.3275825
		{	Oxygen	-	2.6201172
		{	Carbon	-	1.1463758
1.3804254	lbs. of dry yeast, composed of	{	Hydrogen	-	0.1450738
		{	Oxygen	-	0.8218317
		{	Carbon	-	0.3938802
		{	Azot	-	0.0196397
<hr/>					
510	lbs.				510 lbs.

TABLE V. *Recapitulation of the Products.*

		<i>lbs.</i>
409.6308595 <i>lbs.</i> of oxygen contained in the	{ Water -	347.6314019
	{ Carbonic acid -	25.4490017
	{ Alcohol -	31.3897570
	{ Acetous acid -	1.7187500
	{ Residuum of sugar	2.6201172
	{ Yeast -	0.8218317
28.7954643 <i>lbs.</i> of carbon contained in the	{ Carbonic acid -	9.8968099
	{ Alcohol -	16.7333984
	{ Acetous acid -	0.6250000
	{ Residuum of sugar	1.1463758
	{ Yeast -	0.3938802
71.5540365 <i>lbs.</i> of hydro- gen, contain- ed in the	{ Water - -	61.3466797
	{ Water of the alcohol	5.5393880
	{ Combined with the carbon of the alcohol	4.0390625
	{ Acetous acid -	0.1562500
	{ Residuum of sugar	0.3275825
	{ Yeast -	0.1450738
0.0196397 <i>lbs.</i> of azot in the yeast -		0.0196397
<hr/> 510 <i>lbs.</i>		<hr/> 510 <i>lbs.</i>

In the calculation of these results, I have been exact even to minuteness: Not that it is possible, in experiments of this nature, to carry our accuracy so far; but as the experiments were made only with a few pounds of sugar, and as, for the sake of comparison, I reduced the results of the real experiments to the quintal,

or imaginary hundred pounds, I thought it necessary to leave the fractional parts precisely as produced by calculation.

When we consider the results presented by these tables with attention, it is easy to discover exactly what occurs during fermentation. In the first place, out of the 100 *lbs.* of sugar employed, 4.0940755 *lbs.* remain, without having suffered decomposition : so that, in reality, we have only operated upon 95.9059245 *lbs.* of sugar ; that is to say, upon 61.37979168 *lbs.* of oxygen, 7.67247396 *lbs.* of hydrogen, and 26.85365886 *lbs.* of carbon. By comparing these quantities, we find that they are fully sufficient for forming the whole of the alkohol, carbonic acid, and acetous acid, produced by the fermentation. It is not, therefore, necessary to suppose that any water has been decomposed during the experiment, unless it be pretended that the oxygen and hydrogen exist in the sugar already combined in that form. On the contrary, I have already made it evident that hydrogen, oxygen, and carbon, the three constituent elements of vegetable substances, remain in a state of equilibrium, or mutual union with each other, which subsists so long as this union remains undisturbed by increased temperature, or by means of some new compound attraction ; and that then only these elements combine,

two and two together, to form water and carbonic acid.

The effects of the vinous fermentation upon sugar is thus reduced to the mere separation of its elements into two portions ; one part is oxygenated at the expence of the other, so as to form carbonic acid ; while the other part, being difoxygenated in favour of the former, is converted into the combustible substance called alkohol ; therefore, if it were possible to re-unite alkohol and carbonic acid together, we should form sugar. It is evident that the carbon and hydrogen in the alkohol do not exist in the state of oil, but that they are combined with a portion of oxygen, which renders them miscible with water ; wherefore these three substances, oxygen, hydrogen, and carbon, exist here likewise in a species of equilibrium, or reciprocal combination ; and, in fact, when they are made to pass through a red hot tube of glass or porcelain, this union or equilibrium is destroyed ; these elements become recombined two and two, and water and carbonic acid are formed.

I had formerly advanced, in my first Memoirs upon the formation of water, that it was decomposed in a great number of chemical experiments, and particularly during the vinous fermentation. I then supposed that water existed ready formed in sugar, though I am now convinced that sugar only contains the elements

proper for composing it. It may be readily conceived, that it must have cost me a good deal to abandon my first notions. But by several years reflection, and after a great number of experiments and observations upon vegetable substances, I have fixed my ideas as above.

I shall finish what I have to say upon vinous fermentation, by observing, 'that it furnishes us with the means of analysing sugar and every vegetable fermentable matter. We may consider the substances submitted to fermentation, and the products resulting from that operation, as forming an algebraic equation : and, by successively supposing each of the elements in this equation unknown, we can calculate their values in succession, and thus verify our experiments by calculation, and our calculations by experiment, reciprocally. I have often successfully employed this method for correcting the first results of my experiments, and to direct me in the proper road for repeating them to advantage. I have explained myself more at large upon this subject, in a Memoir upon vinous fermentation already presented to the academy, and which will speedily be published.

## C H A P. XIV.

*Of the Putrefactive Fermentation.*

THE phenomena of putrefaction are caused, like those of vinous fermentation, by the operation of extremely complicated affinities. The constituent elements, of the bodies which are submitted to this process, cease to continue in equilibrium, in their original threefold combination, and form themselves anew into binary combinations\*, or compounds consisting of two elements only. But these are entirely different from the results produced by the vinous fermentation. Instead of part of the hydrogen remaining united with part of the water and carbon, to form alcohol, as in the vinous fermentation, the whole of the hydrogen is dissipated, during putrefaction, in the form of hydrogen gas; while, at the same time, the oxygen and carbon, uniting with caloric, escape in the form of carbonic acid; so that, when the whole process is finished, especially if the materials

\* Binary combinations are such as consist of two simple elements combined together. Ternary, and quaternary, consist of three and of four elements.—T.



have been mixed with a sufficient quantity of water, nothing remains but the earth of the vegetable, mixed with a small portion of charcoal and iron. Thus, putrefaction is nothing more than a complete analysis of vegetable substance; during which the whole of the constituent elements is disengaged in form of gas, except the earth, which remains in the state of mould\*.

Such is the result of putrefaction, when the substances submitted to it contain only oxygen, hydrogen, carbon, and a little earth. But this case is rare: and these substances putrify imperfectly and with difficulty, and require a considerable time to complete their putrefaction. It is otherwise with substances containing azot, which indeed exists in all animal matters, and even in a considerable number of vegetable substances. This additional element is remarkably favourable to putrefaction: and for this reason, animal matter is mixed with vegetable, when the putrefaction of these is wished to be hastened. The whole art of forming composts and dunghills, for the purposes of agriculture, consists in the proper application of this admixture.

\* In the third part will be given the description of an apparatus proper for being used in experiments of this kind.—A.

The addition of azot to the materials of putrefaction, not only accelerates the process, but that element likewise combines with part of the hydrogen, and forms a new substance, called *volatile alkali*, or *ammoniac*. The results obtained by analysing animal matters, by different processes, leave no room for doubt with regard to the constituent elements of ammoniac; for, whenever the azot has been previously separated from these substances, no ammoniac is produced; and in all cases they furnish ammoniac only in proportion to the azot they contain. This composition of ammoniac is likewise fully proved by Mr Berthollet, in the memoirs of the Academy for 1781, p. 316, where he gives a variety of analytical processes by which ammoniac is decomposed, and its two elements, azot and hydrogen, procured separately.

I have already mentioned, in Chap. X. that almost all combustible bodies are capable of being combined with each other. Hydrogen gas possesses this quality, of combining with other combustible substances, in an eminent degree. It dissolves carbon, sulphur, and phosphorus, producing the compounds named *carbonated hydrogen gas*, *sulphurated hydrogen gas*, and *phosphorated hydrogen gas*. The two latter of these gasses have a peculiarly disagreeable flavour. The sulphurated hydrogen gas has a strong resemblance to the smell of rotten eggs: and

the phosphorated smells exactly like putrid fish. Ammoniac has likewise a peculiar odour, not less penetrating or less disagreeable than these other gasses. From the mixture of these different flavours, proceeds the foetor which always accompanies the putrefaction of animal substances. Sometimes the ammoniac predominates, which is easily perceived by its sharpness upon the eyes; sometimes, as in feculent matters, the sulphurated gas is most prevalent: and sometimes, as in putrid herrings, the phosphorated hydrogen gas is most abundant.

I long supposed, that nothing could derange or interrupt the course of putrefaction. But Mr Fourcroy and Mr Thouret have observed some peculiar phenomena in dead bodies; buried at a certain depth, and preserved to a certain degree, from contact with air; having found the muscular flesh frequently converted into true animal fat \*. This must have arisen from the disengagement, by some unknown cause, of the azot, naturally contained in the animal substance, leaving only the hydrogen and carbon remaining, which are the elements proper for producing fat or oil. This observa-

\* This process has been lately imitated artificially: and a fatty substance, exactly similar in all respects to Spermaceti, can be readily made from the flesh or muscular parts of all animal bodies.—T.

tion, on the possibility of converting animal substances into fat, may some time or other lead to discoveries of great importance to society. The fæces of animals, and other excrementitious matters, are chiefly composed of carbon and hydrogen; and approach considerably to the nature of oil, of which they furnish a considerable quantity by distillation with a naked fire. But the intolerable foetor, which accompanies all the products of these substances, prevents our expecting that, at least for a long time, they can be rendered useful in any other way than as manures.

I have only given conjectural approximations, in this Chapter, upon the composition of animal substances, which is hitherto imperfectly understood. We know, that they are composed of hydrogen, carbon, azot, phosphorus, and sulphur, all of which, in a state of quintuple combination, are brought to the state of oxyd by a larger or smaller quantity of oxygen. We are, however, still unacquainted with the proportions in which these substances are combined; and must leave it to time to complete this part of chemical analysis, as it has already done with several others.

## CHAP. XV.

*Of the Acetous Fermentation.*

THE acetous fermentation is nothing more than the acidification or oxygenation of wine \*, produced in the open air, by means of the absorption of oxygen. The resulting acid is the acetous acid, commonly called Vinegar, which is composed of hydrogen and carbon united together, in proportions not yet ascertained, and changed into the acid state by oxygen. As vinegar is an acid, we might conclude from analogy, that it contains oxygen : but this is put beyond doubt by direct experiments. In the first place, we cannot change wine into vinegar without the contact of air containing oxygen. Secondly, this process is accompanied by a diminution of the volume of the air in which it is carried on, from the absorption of its oxygen : and thirdly, wine may be changed into vinegar by any other means of oxygenation.

\* The word Wine, in this chapter, is used to signify the liquor produced by the vinous fermentation, whatever vegetable substance may have been used for obtaining it.—T.

Independent of the proofs which these facts furnish, of the acetous acid being produced by the oxygenation of wine, an experiment made by Mr Chaptel, Professor of Chemistry at Montpellier, gives a distinct view of what takes place in this process. He impregnated some water with about its own bulk of carbonic acid from fermenting beer; and placed this water in a cellar, in vessels communicating with the air: and in a short time, the whole was converted into acetous acid. This carbonic acid gas, procured from beer vats in fermentation, is not perfectly pure, but contains a great quantity of alcohol in solution; wherefore water impregnated with it, contains all the materials necessary for forming the acetous acid. The alcohol furnishes hydrogen and one portion of carbon. The carbonic acid furnishes oxygen and the rest of the carbon. And the air of the atmosphere furnishes the rest of the oxygen necessary for changing the mixture into acetous acid. From this observation it follows, that nothing but hydrogen is wanting, to convert carbonic acid into acetous acid; or, more generally, that, by means of hydrogen, and according to the degree of oxygenation, carbonic acid may be changed into all the vegetable acids; and, on the contrary, that, by depriving any of the vegetable acids of their hydrogen, they may be converted into carbonic acid.



Although the principal facts relating to the acetous acid are well known, yet numerical precision is still wanting, until furnished by more exact experiments than any hitherto performed; wherefore I shall not enlarge any farther upon the subject. It is sufficiently shewn by what has been said, that the constitution of all the vegetable acids and oxyds is exactly conformable to the formation of vinegar. But farther experiments are necessary to teach us the proportion of the constituent elements in all these acids and oxyds. We may easily perceive, however, that this part of chemistry, like all the rest of its divisions, makes rapid progress towards perfection; and that it is already rendered greatly more simple than was formerly believed.

## C H A P. XVI.

*Of the Formation of Neutral Salts, and of their different Bases.*

**W**E have just seen, that all the oxyds and acids from the animal and vegetable kingdoms, are formed from a small number of simple elements, by means of combination with oxygen, or at least from such bodies as have not hitherto been susceptible of decomposition, and which must therefore be considered as simple substances, in the present state of our knowledge: these are azot, sulphur, phosphorus, carbon, hydrogen, and the muriatic radical\*. We may justly admire the simplicity of the means employed by nature to multiply qualities and forms, whether by combining three or four acidifiable bases in different proportions, or by

\* I have not ventured to omit this element, as here enumerated with the other principles of animal and vegetable substances, though it is not at all taken notice of in the preceding chapters, as entering into the composition of these bodies. It has been already mentioned, in a former note, that the muriatic radical is now discovered, or at least suspected, to be hydrogen.—T.

altering the dose of oxygen employed for oxydating or acidifying them. We shall find the means no less simple and diversified, and as abundantly productive of forms and qualities, in the order of bodies we are now about to treat of.

Acidifiable substances, by combining with oxygen, and their consequent conversion into acids, acquire a great susceptibility for farther combination. They become capable of uniting with alkaline, earthy, and metallic bodies, by which means neutral salts are formed. Acids may therefore be considered as true *salifying* principles: and the substances with which they unite to form neutral salts may be called *salifiable* bases. The nature of the union which these two principles form with each other, is meant as the subject of the present chapter.

The foregoing view of the acids prevents them from being considered as salts, though they are possessed of many of the principal properties of saline bodies, as solubility in water, &c. It is already observed, that they are the results of a first order of combination, being composed of two simple elements, or at least of elements which act as if they were simple: and they may therefore be ranked, to use the language of Stahl, in the order of *mixts*. The neutral salts, on the contrary, are of a secondary order of combination, being formed by the

union of two *mixts* with each other ; and may therefore be termed *compounds*. Hence I shall not arrange the alkalies\*, or earths, in the class of salts, to which I allot only such as are composed of an oxygenated substance, united to a salifiable base.

I have already enlarged sufficiently upon the formation of acids in the preceding chapter ; and shall not add any thing farther upon that subject. But, having as yet taken no notice of the salifiable bases which are capable of uniting with them to form neutral salts, I mean, in this chapter, to give an account of the nature and origin of each of these bases. These are potash, soda, ammoniac, lime, magnesia, barytes, argill†, and all the metallic bodies.

### § 1. *Of Potash.*

We have already shewn, that, when a vegetable substance is submitted to the action of fire

\* Perhaps thus rejecting the alkalies from the class of salts, may be considered as a capital defect in the method here adopted ; and I am ready to admit the charge. But this inconvenience is compensated by so many advantages, that I could not think it of sufficient consequence to make me alter my plan.—A.

† Called Alumine by Mr Lavoisier. But as Argill has been in a manner naturalized to the language for this substance by Mr Kirwan, I have ventured to use it in preference.—T.

in distilling vessels, its component elements, oxygen, hydrogen, and carbon, which formed a threefold combination in a state of equilibrium, unite two and two, in obedience to affinities which act conformably to the degree of heat employed. Thus, at the first application of the fire, whenever the heat produced exceeds the temperature of boiling water, part of the oxygen and hydrogen unite to form water. Soon after, the rest of the hydrogen, and part of the carbon, combine into oil: and, lastly, when the fire is pushed to the red heat, the oil and water, which had been formed in the early part of the process, become again decomposed; the oxygen and part of the carbon unite to form carbonic acid; a large quantity of hydrogen gas is set free; and nothing but charcoal remains in the retort.

A great part of these phenomena occur during the combustion of vegetables in the open air. But, in this case, the presence of the air introduces three new substances, the oxygen and azot of the air, and caloric: and, of these, two at least produce considerable changes in the results of the operation. In proportion as the hydrogen of the vegetable, or that which arises from the decomposition of the water, is forced out in the form of hydrogen gas, by the progress of the fire, it is set on fire immediately upon coming into contact with the air; water is again formed; and the greater part of the calo-

ric of the two gasses becoming free, produces flame. When all the hydrogen gas is driven out, burnt, and again reduced to water, the remaining carbon continues to burn, but without flame. It is formed into carbonic acid, which carries off a portion of caloric sufficient to give it the gaseous form. The rest of the caloric, from the oxygen of the air, being set free, produces the heat and light observed during the combustion of the carbon. The whole vegetable is thus reduced to water and carbonic acid: and nothing remains but a small portion of grey earthy matter, called ashes, being the only really fixed principles which enter into the constitution of vegetables.

The earth, or rather ashes, which seldom exceeds a twentieth part of the weight of the vegetable, contains a substance of a particular nature, known under the name of fixed vegetable alkali, or potash. To obtain this, water is poured upon the ashes, which dissolves the potash, and leaves the ashes which are insoluble. By afterwards evaporating the water, we obtain the potash in a white concrete form. It is very fixed, even in a very high degree of heat. I do not mean here to describe the art of preparing potash, or the method of procuring it in a state of purity; but have entered into the above detail, merely that I might not use any word, not previously explained.



The potash, obtained by this process, is always less or more saturated with carbonic acid, which is easily accounted for. As the potash does not form, or at least is not set free, but in proportion as the carbon of the vegetable is converted into carbonic acid, by the addition of oxygen, either from the air or the water, it follows, that each particle of potash, at the instant of its formation, or at least of its liberation, is in contact with a particle of carbonic acid: and as there is a considerable affinity between these two substances, they naturally combine together. Although the carbonic acid has less affinity with potash than any other acid, yet it is difficult to separate the last portions from it. The most usual method of accomplishing this, is, to dissolve the potash in water. To this solution two or three times its weight of quicklime are added. Then the liquor is filtrated, and evaporated in close vessels. The saline substance, left by the evaporation, is potash, almost entirely deprived of carbonic acid. In this state, it is soluble in an equal weight of water, and even attracts the moisture of the air with great avidity. By this property it furnishes us with an excellent means of rendering air or gas dry, by exposing them to its action. In this state, it is soluble in alcohol, though not when combined with carbonic acid: and Mr Berthollet employs this property as a method of procuring potash in the state of perfect purity.

All vegetables yield less or more of potash in consequence of combustion; but it is furnished in various degrees of purity by different vegetables: usually, indeed, from whatever source it be procured, it is mixed with different salts, from which, however, it is easily separable. We can hardly entertain a doubt, that the ashes, or earth, which is left by vegetables in combustion, pre-existed in them before they were burnt, forming what may be called the skeleton, or osseous part of the vegetable. But it is quite otherwise with potash. This substance has never yet been procured from vegetables but by means of processes, or intermedia, capable of furnishing oxygen and azot, such as combustion, or by means of nitric acid; so that it is not yet demonstrated that potash may not be a produce from these operations. I have begun a series of experiments upon this subject, and hope soon to be able to give an account of their results.

## § 2. *Of Soda.*

Soda, like potash, is an alkali procured by lixiviation from the ashes of burnt plants, but only from those which grow upon the sea-side, and especially from the herb *kali*, whence is derived the name *alkali*, given to this substance by the Arabians. It has some properties in common with potash, and others which are entirely different. In general, these two substan-

ces have peculiar characters in their saline combinations, which are proper to each, and consequently distinguish them from each other. Thus soda, which, as obtained from marine plants, is usually entirely saturated with carbonic acid, does not attract the humidity of the atmosphere like potash: but, on the contrary, it desiccates; its crystals effloresce, and are converted into a white powder, having all the properties of soda, which it really is, having only lost its water of crystallization.

Hitherto we are not better acquainted with the constituent elements of soda than with those of potash, being equally uncertain whether it previously existed ready formed in the vegetable, or if it be a combination of elements effected by combustion. Analogy leads us to suspect, that azot is a constituent element of all the alkalies, as is the case with ammoniac. But we have only slight presumptions, unconfirmed by any decisive experiments, respecting the composition of potash and soda\*.

\* There are some experiments related in the Transactions of the Turin Academy, which give reason for supposing that soda is a modification of magnesia. This latter substance, according to the experiments detailed by Baron Born, and mentioned in the additional section of this chapter, seems to be a metallic oxyd. From analogy, we may presume, that potash is likewise a metallic substance, in some hitherto unknown state of combination. We shall thus exclude all the alkalies from the class of simple elementary substances.—T.

§ 3. *Of Ammoniac.*

We have, however, very accurate knowledge of the composition of ammoniac or volatile alkali, as it was called by the old chemists. Mr Berthollet, in the memoirs of the academy for 1784, p. 316, has proved by analysis, that 1000 parts of this substance consist of about 807 parts of azot combined with 193 parts of hydrogen.

Ammoniac is chiefly procurable from animal substances by distillation; during which process the azot and hydrogen necessary to its formation unite in proper proportions. It is not, however, procured pure by this process, being mixed with oil and water, and mostly saturated with carbonic acid. To separate these substances, it is first combined with an acid, the muriatic, for instance, and then disengaged from that combination by the addition of lime or potash. When ammoniac is thus produced in its greatest degree of purity, it can only exist under the gaseous form, at least in the usual temperature of the atmosphere. It has an excessively penetrating smell. It is absorbed in large quantities by water, especially if cold, and assisted by compression. Water, thus saturated with ammoniac, has usually been termed volatile alkaline fluor. We shall call it either simply ammoniac, or liquid ammoniac, and ammoniacal gas, when it exists in the æriform state\*.

\* The nomenclature of the alkalies proposed by Dr Black, seems better than that adopted by Mr Lavoisier and the

§ 4. *Of Lime, Magnesia, Barytes, and Argill.*

The composition of these four earths is totally unknown; and, until by new discoveries their constituent elements are ascertained, we are certainly authorised to consider them as simple bodies. Art has no share in the production of these earths; as they are all procured ready formed from nature. But, as they have all, especially the three first, great tendency to combination, they are never found pure. Lime is usually saturated with carbonic acid in the state of chalk, calcareous spars, most of the marbles, &c.; sometimes with sulphuric acid, as in gypsum and plaster stones; at other times with fluoric acid forming vitreous or fluor spars; and, lastly, it is found in the waters of the sea, and of saline springs, combined with muriatic acid. Of all the salifiable bases, it is the most universally spread through nature.

Magnesia is found in mineral waters, for the most part combined with sulphuric acid. It is likewise abundant in sea-water, united with muri-

French chemists. *Lixa, trona*, and *ammonia*, are equally convenient for use as potassa or potash, soda, and ammoniac, and they are not so apt to lead into mistakes; for the words of the new French chemical nomenclature have too much resemblance to old terms used for very different substances, or at least for very different states, in a chemical light, of the same substances.—T.

atic acid : and it exists in a great number of stones of different kinds.

Barytes is much less common than the two preceding earths. It is found in the mineral kingdom, combined with sulphuric acid, forming heavy spars, and sometimes, though rarely, united to carbonic acid.

Argill, or the base of alum, having less tendency to combination with the other earths, is often found in the state of argill, uncombined with any acid. It is chiefly procurable from clays, of which, properly speaking, it is the base, or chief ingredient \*.

“ On the 4th of November 1793, Dr Hope, now associated in the Edinburgh chemical chair, with Dr Black, read to the Royal Society of Edinburgh, a very elaborate analysis of a non-descript mineral, from the mines of Strontian in Argyleshire ; to which, from its place and structure, he gives the name of *Strontitic spar* ; and which he finds to consist of a peculiar earth, hitherto undiscovered in any other mineral body, combined with carbonic acid. To this earth he has assigned the name of *Strontites*, which agrees very well with the new nomenclature ; only that, perhaps, Strontita would have been more regular, for the reasons mentioned in the two preceding notes. In this elementary treatise, a detailed ac-

\* For reasons similar to those given in the preceding note, Dr Black proposes to name these four simple earths, Calca, Magnesia, Baryta, and Argal.—T.



count of this important discovery cannot be given ; for which the reader is referred to the Transactions of the Royal Society of Edinburgh. Strontites has a pungent acrid taste ; is soluble both in hot and cold water, but much more so in hot, from which it crystallizes in cooling ; its cold solutions attract carbonic acid from the atmosphere, form a crust of carbonate of Strontites on the surface, which breaks and falls to the bottom, exactly as in lime, and is redissolved by an excess of acid. Strontites combines with the various acids, forming neutral salts ; and possesses different affinities with the acids from the other known earths. One of its most remarkable properties, both when pure and in combination with the acids, is that of tinging the flame of combustible bodies of a deep blood red colour ; to produce which effect, however, some moisture must be present. The order of affinities of the principal acids with Strontites, as determined by Dr Hope's experiments, is as follows :

Sulphuric.	Nitric.	Acetous.
Oxalic.	Muriatic.	Arseniac.
Tartarous.	Succinic.	Boracic.
Fluoric.	Phosphoric.	Carbonic.

Its order of affinities with the several acids, relative to the other salifiable bases, so far as ascertained by Dr Hope, are inserted in the respective tables in Part II.\*"

\* The whole of this account of Strontites, has been added to the third Edition.—T.

§ 5. *Of Metallic Bodies.*

The metals, except gold, and sometimes silver, are rarely found in the mineral kingdom in their metallic state, being usually less or more saturated with oxygen, or combined with sulphur, arsenic, sulphuric acid, muriatic acid, carbonic acid, or phosphoric acid. Metallurgy, or the domestic art, teaches the means of separating them from these foreign matters; and for this purpose we refer to such chemical books as treat upon these operations.

We are probably only acquainted as yet with a part of the metallic substances existing in nature; as all those which have a stronger affinity to oxygen than carbon possesses, are incapable, hitherto, of being reduced to the metallic state: and, consequently, being only presented to our observation under the form of oxyds, are confounded with earths. It is extremely probable, that barytes, which we have just now arranged with earths, is in this situation; for in many experiments it exhibits properties nearly approaching to those of metallic bodies. It is even possible, that all the substances we call earths, may be only metallic oxyds, irreducible by any hitherto known process.

Those metallic bodies we are at present acquainted with, and which we can reduce to the

metallic or reguline state, are the following seventeen.

<i>Latin Names.</i>		<i>English Names.</i>
1. Arfenicum	-	Arfenic.
2. Molybdenum	-	Molybdena.
3. Tungstenum	-	Tungstein.
4. Manganefum	-	Manganefe.
5. Nickolum	-	Nickel.
6. Cobaltum	-	Cobalt.
7. Bismuthum	-	Bismuth.
8. Antimonium	-	Antimony.
9. Zincum	-	Zinc.
10. Ferrum	-	Iron.
11. Stannum	-	Tin.
12. Plumbum	-	Lead.
13. Cuprum	-	Copper.
14. Mercurium	-	Mercury.
15. Argentum	-	Silver.
16. Aurum	-	Gold.
17. Platinum	-	Platina.

I only mean to confider these as falifiable bafes, without entering at all upon the confideration of their properties in the arts, and for the ufes of fociety. In thefe points of view, each metal would require a complete treatife, which would lead me far beyond the bounds I have prefcribed for this work.

§ 6. *Of the Metallic Nature of the Earths* \*.

In the laboratory of the Academy of the mines at Chemnitz, in Lower Hungary, some experiments have been lately made, by Messrs Tondi and Ruprecht, by which the number of the metals seems to be considerably augmented. Besides ascertaining the real metallic nature of Tungstein, Molybdena, and Manganese, which some chemists had doubted, but all of which have been reduced to the reguline form by these two chemists, they have succeeded in procuring metallic reguli from Chalk, Magnesia, and Barytes. Of these experiments it may be proper to give some account in this place, from the description of the cabinet of Mademoiselle Raab, of Vienna, by Baron Born.

*Barytes.*

After having purified some Barytes, by repeated fusions and precipitations, it was mixed with an eighth part of its weight of powdered charcoal, and made into a paste with lintseed oil. This was put into a crucible, surrounded by powdered charcoal, and submitted to a strong melting heat, for an hour and a half. A perfect metallic regulus was procured, of an iron-grey

\* The whole of this section was added by the Translator to the second edition.

colour and uniform metallic lustre. Its texture is lamellated, composed of large distinct lamellæ, which cross each other. It is brittle, but not hard, and readily takes a polish; is attracted by the magnet, notwithstanding every possible precaution to separate any martial oxyd which might have previously been mixed with the mineral. The specific gravity of this new metal is 6.744, water being taken as unity.

*Magnesia.*

By treating the carbonat of magnesia in the same manner, they obtained a convex lump or globule of metallic regulus, of a bright grey colour, similar to platina which has not been fully purified from iron. This regulus is harder than those obtained from tungstein or molybdena. It is granular, and somewhat striated in its texture, when broken; and is not affected by the magnet. Its specific gravity, and other properties, have not yet been ascertained.

*Chalk.*

By the same method of proceeding, a regulus has likewise been procured from carbonat of chalk. The button was convex, and very compact in its texture. In colour and lustre it came very near to the appearance of platina; and it took a fine polish. Its specific gravity, and chemical rela-

tions, have not yet been ascertained by experiment.

These experiments have been frequently repeated by the above-mentioned gentlemen, and always with the same results. Should they eventually be confirmed by rigorous examination, a new light will be thrown on several of the most difficult parts of chemistry by these discoveries, which have already been in a great measure predicted, by the conjecture of Mr Lavoisier, who supposes that those substances, which have long been considered as primitive earths, are only metallic oxyds, combined with oxygen; and that their reduction has hitherto been prevented by the attraction which subsists between them and oxygen being stronger than that between oxygen and carbon.

Mr Baron Born adds to the above account, “ that he expects soon to learn, that the silicious  
“ and argillaceous earths are likewise metallic  
“ oxyds; and that, in this case, the whole class  
“ of earths and stones will disappear from the  
“ mineral kingdom. The discovery is certainly  
“ one of the most important that modern chemistry has produced for a long while. It must  
“ have great influence in changing our metallurgic processes, which will thereby become  
“ more certain in their results, and more scientific in their application. Even every branch  
“ of chemistry may receive considerable light



“ and improvement from their influence. Per-  
 “ haps gold and silver are the only pure metal-  
 “ lic substances hitherto known; as it is proba-  
 “ ble, that some part of the, till now unknown,  
 “ metals, from the earths employed for facilita-  
 “ ting the smelting of ores, may mix with the  
 “ metals which we extract from these ores, and  
 “ debase them; so that, instead of simple or  
 “ pure metals, which they were formerly con-  
 “ sidered, these may only be alloys, of the in-  
 “ gredients of which we are still ignorant. Per-  
 “ haps the reguli of barytes and of chalk are  
 “ soluble in the same acids, and precipitated by  
 “ the same elective attractions, as the regulus  
 “ of copper, which may be the cause of this  
 “ mixture not being hitherto suspected. From  
 “ this mixture, or alloyage, the harshness and  
 “ greater or lesser ductility of iron, copper, tin,  
 “ and other metals, may be derived. All these  
 “ conjectures can only be ascertained or reject-  
 “ ed, when all these newly-discovered metals  
 “ shall have been properly examined, and their  
 “ chemical affinities compared accurately with  
 “ those of the metals already known, and with  
 “ each other. One thing seems highly proba-  
 “ ble, that one or other of these new metals  
 “ will precipitate some of the other metals from  
 “ solutions in a metallic form: and by this pro-  
 “ perty many metallurgic processes may become  
 “ greatly facilitated and abridged.”

These discoveries give reason to hope, that chemistry may one day arrive at a most beautiful state of simplicity. It is, perhaps, no improbable conjecture, that all the bodies in nature may be referred to one class of simple combustible elementary substances, to oxygen, and to caloric; and that, from the various combinations of these with each other, all the variety produced by nature and art may arise. The only known difference between metals and pure combustibles, as they are called, is in degrees of qualities. They are all combustible, that is, they all combine with oxygen, though under different degrees of temperature. They are all solid, or liquid, or æriform, fixed, or volatile, at different temperatures. In different degrees of saturation with oxygen, they form oxyds, which have alkaline properties, or acids. In the state of oxyds, the formerly known metals have all the properties of what were formerly called primitive earths, which are now at least suspected of being metallic oxyds. Even the æriform nature of hydrogen and azot, which does not separate them from the rest so far as combustibility is concerned, is only a difference in degree of volatility. We do not exclude mercury from the metals, because it is volatile in the temperature of  $600^{\circ}$ , and fuses at  $-40^{\circ}$ , though iron is fixed at  $24000^{\circ}$ , according to Mr Wedgwood's experiments, and requires  $25077^{\circ}$  for its fusion. Why then should hydrogen and azot be

excluded from a class with which they agree in so many particulars, because their points of fusion and volatility are perhaps as many degrees below those belonging to mercury, as this latter falls short of those of iron : or why should carbon, sulphur, and phosphorus, not be considered as metals, because their specific gravity, and lustre, and ductility, differ from the bodies called metals, which differ so much in these particulars among themselves ?

To these three new metals, Mr Tondi wishes to give the names of *borbonium*, for the regulus of barytes ; *austrium*, for the regulus from magnesia ; and *parthenum* for that of chalk. It were hard to deny a discoverer the right of giving names to his own discoveries, without some reasonable objection. But these names would introduce confusion into chemical nomenclature, which it has been the great object of the French chemists to reform, and render regular ; wherefore I would propose that they should be named *barytum*, *magnesium*, and *calcum*. These accord with the reformed old names of the substances from which they are procured, merely by changing to the neuter gender, in which all the names of the metals are placed in the new nomenclature : and then the three, formerly called, earths will be oxyds of these metals respectively, or *baryta*, *magnesia*, and *calca*, if single terms are preferred, these latter being in the femi-

nine gender, which is appropriated to alkaline substances in the new nomenclature.

It must not, however, be concealed, that the truth of these discoveries is strongly contested by very eminent chemists; who insist, that the metallic buttons produced in the experiments of Messrs Tondi and Ruprecht, arise entirely from the manganese and iron of the charcoal, or from some similar alloyage of materials from the crucibles or tests employed; and that they have no farther pretensions to be considered as distinct metals than the siderite, now known to be phosphorated iron, or than plumbago, or black-lead.

Mr Klaproth a celebrated chemist at Berlin, has lately discovered a new metal, to which he gives the name of Uranium; and he distinguishes its various mineral forms by the generic term of Uranite. His numerous experiments on this subject, are published in *Crell's Chemical Journal*, and in the *Annales de Chymie*: and the following general account of the minerals, and of the metal, was considered as proper to be given in this place.

The Uranite occurs in several forms, which were formerly overlooked, by chemists and mineralogists, being considered as very poor ores of copper, because they mostly contain a little of that metal. They are chiefly found near Johann-georgen Stadt in Saxony, Salfeldt in Thuringia, and Joachimsthal in Bohemia.

These may be divided into three genera, the ochreous, the spathiform, and the mineralized, or ore. The ochreous, or uranite ochre, called *uranite-oker*, in the German language, is of a lemon yellow colour, of various shades : and being frequently more or less mixed with iron ochre, its colour is thereby changed to various shades of brown. Sometimes it is in a powdery state ; and at other times it is caked together in masses of different degrees of compactness. It is generally found covering or adhering to pieces of the mineralized uranite. The spathiform, or uranite spar, called in German *uranit-spath*, the *chalkolith* of Mr Werner, is generally of a deep grass green colour, sometimes verging to a silver white, and at other times to a light yellowish green. It is sometimes compact and irregular in its form ; and is sometimes crystallized in small shining square and transparent tables, which are occasionally so thick as to be almost cubes. These crystals are lamellated in the fracture, and feel soft to the touch. They are often found in spots, scattered over the surface of micaceous schist, granite, or a mixture of quartz and black uranite ore. Both the ochre and spar dissolve entirely in nitric acid. The mineralized, or uranite ore, called in German *uranit-erz*, *pech-blende*, or *pech-erz*, is of a dark black-brown colour. It is tolerably hard, has a greasy lustre, breaks compact, and is black where scratched. It is very heavy,

the specific gravity being 7.500. It does not melt in the fire by itself; but is reduced under the blow-pipe, with the addition of phosphoric acid, to a green vitreous globule. It dissolves imperfectly in the acids, but best in the nitrous, the dissolution being of a pale white-wine colour.

Uranium, the metal procured from these mineral substances, is even more difficultly fused than manganese. Its specific gravity is 6.440. It is of a dark grey colour, becoming brown when scratched. Its brilliancy is slight: and it is rather soft, being easily cut with a knife or file. It dissolves very imperfectly in the sulphuric and muriatic acids, but very readily, and with considerable evolution of heat, in nitric and nitro-muriatic acids. From this dissolution, its oxyd is precipitated of a yellow colour, by the pure alkalies; and the precipitates are re-dissolved by an excess of alkali. With the alkaline carbonats, the precipitates are whitish, and reddish brown when the prussiate is employed. These oxyds do not melt under the blow-pipe, without addition: but with soda and borax, they melt into a brown button; and with phosphoric acid the button is of a green colour.



## CHAP. XVII.

*Continuation of the Observations upon Salifiable Bases, and the Formation of Neutral Salts.*

IT is necessary to remark, that earths and alkalies unite with acids to form neutral salts without the intervention of any medium; whereas metallic substances are incapable of forming this combination, without being previously less or more oxygenated. Strictly speaking, therefore, metals are not soluble in acids, but only metallic oxyds. Hence, when a metal is put into an acid for solution, it is necessary, in the first place, that it become oxygenated, either by attracting oxygen from the acid, or from the water with which the acid is diluted; or, in other words, that a metal cannot be dissolved in an acid, unless the oxygen, either of the acid, or of the water mixed with it, has a stronger affinity to the metal than to the hydrogen or the acidifiable base; or, what amounts to the same thing, that no metallic dissolution can take place, without a previous decomposition of the water, or of the acid in which it is made. The explanation of the principal phenomena of me-

tallic dissolution depends entirely on this simple observation, which was overlooked even by the illustrious Bergman.

The first and most striking of these phenomena is the effervescence, or, to speak less equivocally, the disengagement of gas, which takes place during the solution. In the solutions made in nitric acid, this effervescence is produced by the disengagement of nitrous gas. In solutions with sulphuric acid, it is either sulphurous acid gas or hydrogen gas, according as the oxydation of the metal happens to be made at the expence of the sulphuric acid or of the water. As both nitric acid and water are composed of elements, which, when separate, can only exist in the gaseous form, at least in the common temperature of the atmosphere, it is evident, that, whenever either of these is deprived of its oxygen, the remaining element must instantly expand and assume the state of gas. The effervescence is occasioned by this sudden conversion from the liquid to the gaseous state. The same decomposition, and consequent formation of gas, takes place when solutions of metals are made in sulphuric acid. In general, especially by the humid way, metals do not attract all the oxygen it contains. They therefore reduce it, not into sulphur, but into sulphurous acid; and as this acid can only exist as gas in the usual tem-

perature, it is disengaged, and occasions effervescence.

The second observable phenomenon is, that, when the metals have been previously oxydated, they all dissolve in acids without effervescence. This is easily explained; because, not having now any occasion for combining with oxygen, they neither decompose the acid nor the water, by which decomposition, in the former case, the effervescence is occasioned.

A third phenomenon, which requires particular consideration, is, that none of the metals produce effervescence by solution in oxygenated muriatic acid. During this process, the metal, in the first place, carries off the excess of oxygen from the oxygenated muriatic acid, by which it becomes oxydated, and reduces the acid to the state of ordinary muriatic acid. In this case there is no production of gas; not that the muriatic acid does not tend to exist in the gaseous state in the common temperature, which it does equally with the acids formerly mentioned, but because this acid, which otherwise would expand into gas, finds more water combined with the oxygenated muriatic acid, than is necessary to retain it in the liquid form. Hence it does not disengage like the sulphurous acid, but remains, and quietly dissolves and combines with the metallic oxyd previously formed from its superabundant oxygen.

The fourth phenomenon worthy of notice is, that metals are absolutely insoluble in such acids as have their bases joined to oxygen by a stronger affinity than these metals are capable of exerting upon that acidifying principle. Hence silver, mercury, and lead, in their metallic states, are insoluble in muriatic acid; but, when previously oxydated, they become readily soluble without effervescence.

From these phenomena it appears, that oxygen is the bond of union between metals and acids: and from this we are led to suppose, that oxygen is contained in all substances which have a strong affinity with acid. Hence it is very probable, that the four eminently salifiable earths contain oxygen, and that their capability of uniting with acids is produced by the intermediation of that element. What I have formerly noticed, relative to these earths, viz. that they may very possibly be metallic oxyds, with which oxygen has a stronger affinity than with carbon, and consequently are not reducible by any known means, is considerably strengthened by the above considerations.

All the acids hitherto known, are enumerated in the following table. The first column contains the names of the acids, according to the new nomenclature, in Latin; in the second column, the English names, according to the same no-

menclature are placed; the third contains the bases or radicals of these acids.

*Table of all the known Acids.*

<i>Latin Names.</i>	<i>English Names.</i>	<i>Bases.</i>
1. Acidum fulphurosum	Sulphurous acid	} Sulphur
2. — sulphuricum	Sulphuric	
3. — phosphorosum	Phosphorous	} Phosphorus
4. — phosphoricum	Phosphoric	
5. — muriaticum	Muriatic	} Unknown†
6. — oxygenatum*	Oxygenated muriatic	
7. — nitrosum	Nitrous	} Azot.
8. — nitricum	Nitric	
9. — oxygenatum‡	Oxygenated nitric	}
10. — carbonicum	Carbonic	
11. — acetosum	Acetous	} Compound. See Obs. 1st.
12. — aceticum	Acetic	
13. — oxalicum	Oxalic	
14. — tartarosum	Tartarous	
15. — pyro-tartarosum	Pyro-tartarous	
16. — citricum	Citric	
17. — malicum	Malic	
18. — pyro-lignosum	Pyro lignous	
19. — pyro-mucosum	Pyro-mucous	

\* This term might be changed for Acidum murioxicum, Murioxic acid.—T.

† In a former note, Hydrogen is mentioned as the supposed base of this acid.—T.

‡ This might more conveniently be named Acidum nitroxicum, or Nitroxic acid.—T.

<i>Latin Names.</i>	<i>English Names.</i>	<i>Bases.</i>
20. Acidum gallicum	Gallic	} Compound, See Obs. 2.
21. — prussicum	Prussic	
22. — benzoicum	Benzoic	
23. — succinium	Succinic	
24. — camphoricum	Camphoric	
25. — lacticum	Lactic	
26. — saccho-lacticum	Saccho-lactic	} Compound, See Obs. 3d.
27. — bombicum	Bombic	
28. — formicum	Formic	
29. — sebicum	Sebacic	} Unknown
30. — boracicum	Boracic	
31. — fluoricum	Fluoric	
32. — antimonicum	Antimonic	Antimony
33. — argenticum	Argentick	Silver
34. — arseniacum	Arsenic*	Arsenic
35. — bismuthicum	Bismuthic	Bismuth
36. — cobalticum	Cobaltic	Cobalt
37. — cupricum	Cupric	Copper
38. — stannicum	Stannic	Tin
39. — ferricum	Ferric	Iron
40. — manganicum	Manganic	Manganese
41. — mercuricum †	Mercuric	Mercury
42. — molybdicum	Molybdic	Molybdena
43. — nickolicum	Nickolic	Nickel
44. — auricum	Auric	Gold.

\* This term differs a little from the general rule, in making the name terminate in *ac* instead of *ic*. The base and acid are distinguished in French by *Arsenic* and *Arsenique*; but, as the syllable *ic* was thought most convenient for the English translation of the French *ique*, it became necessary to use this small deviation.—T.

† Mr Lavoisier has *Hydrargirique*; but Mercurium being used for the metal or base, the name of this acid, as above, is at least equally regular, and less harsh.—T.



<i>Latin Names.</i>	<i>English Names.</i>	<i>Bases.</i>
45. Acidum platinicum	Platinic	Platina
46. —plumbicum	Plumbic	Lead
47. —tungsticum	Tungstic	Tungstein
48. —zincicum	Zincic	Zinc

*Observations on the foregoing Table.*

1<sup>st</sup>, The bases or radicals of the acids, from N° 11. to N° 19. inclusive, seem to be formed by a combination of carbon and hydrogen : and the only difference appears to proceed from the dissimilar proportions in which these elements combine to form the bases of these acids, together with the different quantities of oxygen in their acidification. A connected series of accurate experiments is still wanted, to illustrate this subject in a satisfactory manner.

2<sup>d</sup>, The bases or radicals of the acids, from N° 20. to 26. inclusive, are hitherto very imperfectly known. We only know, that hydrogen and carbon are their principal elements, and that the prussic acid contains likewise some azot.

3<sup>d</sup>, The bases of the acids 27, 28, 29, and all others obtained from animal substances, are still very imperfectly known, and require farther investigation ; for they seem to consist of carbon, hydrogen, phosphorus, and azot, united together : but the particular proportions of these elements in each, and the degrees of oxydation, are unascertained.

In this list, which contains 48 acids, I have enumerated 17 metallic acids, hitherto very imperfectly known\*, but upon which Mr Berthollet is about to publish a very important work. It cannot be pretended that all the acids which exist in nature, or rather all the acidifiable bases, are yet discovered. But on the other hand, there are considerable grounds for supposing, that a more accurate investigation than has hitherto been attempted, will diminish the number of the vegetable acids, by shewing, that several of these, at present considered as distinct acids, are only modifications of others. All that can be done, in the present state of our knowledge, is, to give a view of chemistry, as it really is, and to establish fundamental principles, by which such bodies as may be discovered in future, may receive names, in conformity with one uniform system.

The known salifiable bases, or substances capable of being converted into neutral salts, by union with acids, amount to 24; viz. 3 alkalies, 4 earths, and 17 metallic substances; so that, in the present state of chemical knowledge, the whole possible number of neutral salts amounts

\* The list might have been augmented by the probable acids from the newly discovered metals, mentioned in the additional section of the former chapter. It is not impossible that the bases of the Boracic and Fluoric acids may hereafter be discovered among these new metals.—T.

to 1152 \*. This number is upon the supposition, that the metallic acids are capable of dissolving other metals, which is a new branch of chemistry, not hitherto investigated, upon which depends all the metallic combinations named *vitreous*. There is reason to believe, that many of these supposable saline combinations are not capable of being formed, which must greatly reduce the real number of neutral salts producible by nature and art. Even if we suppose the real number to amount only to five or six hundred species of possible neutral salts, it is evident, that, were we to distinguish them, after the manner of the older chemists, either by the names of their first discoverers, or by terms derived from the substances from which they are procured, we should at last have such a confusion of arbitrary designations, as no memory could possibly retain. This method might be tolerable in the early ages of chemistry, or even till within these twenty years, when only about thirty species of salts were known. But, in the present times, when the number is augmenting daily, when every new acid gives us 24 or 48 new salts, according as it is capable of one or

\* This number excludes all triple salts, or such as contain more than one salifiable base, all the salts whose bases are over or under saturated with acid, and those formed by the nitromuriatic acid.—T.

two degrees of oxygenation, a new method is certainly necessary. The method here adopted, drawn from the nomenclature of the acids, is perfectly analogical; and, following Nature in the simplicity of her operations, gives a natural and easy nomenclature, applicable to every possible neutral salt.

In giving names to the different acids, we have expressed the common property by the generic term *acid*, and have distinguished each species, by the name of its peculiar acidifiable base. Hence the acids formed by the oxygenation of sulphur, phosphorus, carbon, &c. are called *sulphuric acid*, *phosphoric acid*, *carbonic acid*, &c. We thought it proper, likewise, to indicate the different degrees of saturation with oxygen, by different terminations of the same specific names: Wherefore we distinguish between sulphurous and sulphuric, and between phosphorous and phosphoric acids, &c.

By applying these principles to the nomenclature of neutral salts, we use a common term for all the neutral salts arising from the combinations of one acid, and distinguish the species, by adding the name of the salifiable base. Thus, all the neutral salts having sulphuric acid in their composition, are named *sulphats*; those formed by the phosphoric acid, *phosphats*, &c. The species being distinguished by the names of the salifiable bases, gives us *sulphat of potash*, *sulphat of*

*soda, sulphat of ammoniac, sulphat of lime, sulphat of iron, &c.* As we are acquainted with 24 salifiable bases, alkaline, earthy, and metallic, we have consequently 24 sulphats, as many phosphats, and so on through all the acids.

Sulphur is, however, susceptible of two degrees of oxygenation, the first of which produces sulphurous, and the second, sulphuric acid: and, as the neutral salts produced by these two acids, have different properties, and are in fact different salts, it becomes necessary to distinguish those by peculiar terminations. We have therefore distinguished the neutral salts formed by the acids in the first or lesser degree of oxygenation, by changing the termination *at* into *ite*, as *sulphites, phosphites\**, &c. Thus, oxy-

\* As all the specific names of the acids in the new nomenclature are adjectives, they would have applied severally to the various salifiable bases, without the invention of other terms, with perfect distinctness. Thus, *sulphurous potash*, and *sulphuric potash*, are equally distinct, as *sulphite of potash*, and *sulphat of potash*; and have the advantage of being more easily retained in the memory, because more naturally arising from the names of acids themselves, than the arbitrary terminations adopted by Mr Lavoisier. These proposed terms are likewise very readily and distinctly expressible in Latin, thus, *Potassa*, or rather, as I have formerly observed, *Lixa*, *Sulphurosa*, and *Sulphurica*, and are equally distinctive with, and more readily remembered than, the Latin terms of the new nomenclature, *Sulphis* and *Sulphas Potassæ*.—T.

generated or acidified sulphur, in its two degrees of oxygenation, is capable of forming 48 neutral salts, 24 of which are sulphites, and as many sulphats. This is likewise the case with all the acids capable of two degrees of oxygenation\*.

It were both tiresome and unnecessary to follow these denominations through all the varieties of their possible applications. It is enough to have given the method of naming the various salts, which, when once well understood, is easily applicable to every possible combination. The name of the combustible and acidifiable body being once known, the names of the acid it is capable of forming, and of all the neutral combinations the acid is susceptible of en-

\* There is yet a third degree of oxygenation of several acids, as the oxygenated muriatic and oxygenated nitric acids. The terms applicable to the neutral salts resulting from the union of these acids with salifiable bases are supplied by the Author in the Second Part of this Work. These are formed by prefixing the word *oxygenated* to the name of the salt produced by the second degree of oxygenation. Thus, *oxygenated* muriat of potash, *oxygenated* nitrat of soda, &c. Or if the change I have proposed in a former note, on the nomenclature of these two acids, be adopted, we shall have *murioxic* and *nitroxie* potash or lixa, in Latin *Lixa murioxica*, *Trona nitroxica*, instead of the much longer, and not more distinctive expressions, *Murias potassæ oxygenata*, *Nitras sodæ oxygenata*.—T.



tering into, are most readily remembered. Such as require a more complete illustration of the methods in which the new nomenclature is applied, will, in the second Part of this book, find Tables which contain a full enumeration of all the neutral salts, and, in general, of all the possible chemical combinations, so far as is consistent with the present state of our knowledge. To these I shall subjoin short explanations, containing the best and most simple means of procuring the different species of acids, and some account of the general properties of the neutral salts they produce.

I shall not deny, that, to render this work more complete, it would have been necessary to add particular observations upon each species of salt; its solubility in water and alcohol; the proportions of acid and of salifiable base in its composition; the quantity of its water of crystallization; the different degrees of saturation it is susceptible of; and finally, the degree of force or affinity with which the acid adheres to the base. This immense work has been already begun by Mess. Bergman, Morveau, Kirwan, and other celebrated chemists; but is hitherto only in a moderate state of advancement. Even the principles upon which it is founded are not perhaps sufficiently accurate.

These numerous details would have swelled this elementary treatise to much too great a size ; besides that, to have gathered the necessary materials, and to have completed all the series of experiments requisite, must have retarded the publication of this book for many years. This is a vast field for employing the zeal and abilities of young chemists, whom I would advise to endeavour rather to do *well* than to do *much*, and to ascertain, in the first place, the composition of the acids, before entering upon that of the neutral salts. Every edifice which is intended to resist the ravages of time, should be built upon a sure foundation : and, in the present state of chemistry, to attempt discoveries by experiments, either not perfectly exact, or not sufficiently rigorous, will serve only to interrupt its progress, instead of contributing to its advancement.

## PART II.

*Of the Combination of Acids with Salifiable Bases,  
and of the Formation of Neutral Salts.*

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## INTRODUCTION.

IF I had strictly followed the plan at first laid down for the conduct of this work, I would have confined myself, in the Tables and accompanying observations which compose this Second Part, to short definitions of the several known acids, and abridged accounts of the processes by which they are obtainable, with a mere nomenclature or enumeration of the neutral salts which result from the combination of these acids with the various salifiable bases. But I afterwards found, that the addition of similar Tables of all the simple substances which enter

into the composition of the acids and oxyds, together with the various possible combinations of these elements, would add greatly to the utility of this work, without being any great increase to its size. These additions, which are all contained in the twelve first sections of this Part, and the Table annexed to these, form a kind of recapitulation of the first fifteen Chapters of the First Part ; the rest of the Tables and Sections contain all the saline combinations.

It must be very apparent, that, in this Part of the Work, I have borrowed largely from what has been already published by Mr de Morveau in the First Volume of the *Encyclopedie par ordre des Matieres*. I could hardly have discovered a better source of information, especially when the difficulty of consulting books in foreign languages is considered. I make this general acknowledgment on purpose to save the trouble of references to Mr de Morveau's work, in the course of the following part of mine.

## TABLE OF SIMPLE SUBSTANCES.

Simple substances belonging to all the kingdoms of Nature, which may be considered as the chemical elements of bodies.

<i>New Names.</i>		<i>Correspondent old Names.</i>
<i>English.</i>	<i>Latin.</i>	
Light		Light.
Caloric	Caloricum	{ Heat, Principle or element of heat. Fire, Igneous fluid, Matter of fire and heat. Dephlogisticated air, Empyrean air, Vital air, or Base of vital air. Phlogisticated air or gas, Mephitic, or its base. Inflammable air or gas, or the base of inflammable air.
Oxygen	Oxygenum	
Azot	Azotum	
Hydrogen	Hydrogenum	

## Oxydable and Acidifiable simple Substances not metallic.

<i>New Names.</i>		<i>Correspondent old Names.</i>
Sulphur	Sulphurum	} The same names.
Phosphorus	Phosphorum	
Carbon	Carbonum	} The simple elements of charcoal
Muriatic radical	Murium	
Fluoric radical	Fluorum	} Still unknown.
Boracic radical	Boracum	

## Oxydable and acidifiable simple Metallic Bodies

<i>New Names.</i>		<i>Correspondent old Names.</i>
Antimony	Antimonium	{ Regulus of Antimony. Arsenic. Bismuth. Cobalt. Copper. Gold. Iron. Lead. Manganese. Mercury. Molybdena. Nickel. Platina.
Arsenic	Arsenicum	
Bismuth	Bismuthum	
Cobalt	Cobaltum	
Copper	Cuprum	
Gold	Aurum	
Iron	Ferrum	
Lead	Plumbum	
Manganese	Manganum	
Mercury	Mercurium	
Molybdena	Molybdenum	
Nickel	Nickolum	
Platina	Platinum	

Silver	Argentum	}	{	Silver.
Tin	Stannum			Tin.
Tungstein	Tungstenum			Tungstein.
Zinc	Zincum			Zinc.

Salifiable simple Earthy Substances.

<i>New Names</i>		<i>Correspondent old Names</i>	
<i>Englsh.</i>	<i>Latin.</i>		
Lime	Calca	{	Chalk, calcareous earth,
			Quicklime.
Magnesia	Magnesia	{	Magnesia, base of Epsom salt,
			Calcined or caustic magnesia.
Barytes	Baryta		Barytes, or heavy earth.
Argill	Argilla		Clay, earth of alum.
Silex	Silica		Silicious or vitrifiable earth.
Strontites	Strontyta		Newly discovered.

### SECT. I. *Observations upon the Table of Simple Substances.*

The principal object of chemical experiments is to decompose natural bodies, so as separately to examine the different substances which enter into their composition. By consulting chemical systems, it will be found, that this science of chemical analysis has made rapid progress in our times. Formerly oil and salt were considered as elements of bodies: whereas later observation and experiment have shewn, that all salts, instead of being simple, are composed of an acid united to a base. The bounds of analysis have been greatly enlarged by modern discoveries\*. The acids are shewn to be composed

\* See Memoirs of the academy for 1766, p. 671, and for 1778, p. 535.—A.



of oxygen, as an acidifying principle common to all, united in each to a particular base. I have proved, what Mr Hassenfratz had before advanced, that these radicals of the acids are not all simple elements, many of them being, like the oily principle, composed of hydrogen and carbon. Even the bases of neutral salts have been proved, by Mr Berthollet, to be compounds; as he has shewn, that ammoniac is composed of azot and hydrogen.

Thus, as chemistry advances towards perfection, by dividing and subdividing, it is impossible to say where it is to end: and these things we at present suppose simple, may soon be found quite otherwise. All we dare venture to affirm of any substance, is, that it must be considered as simple in the present state of our knowledge, and so far as chemical analysis has hitherto been able to show. We may even presume, that the earths must soon cease to be considered as simple bodies. They are the only bodies of the salifiable class which have no tendency to unite with oxygen; and I am much inclined to believe that this proceeds from their being already saturated with that element. If so, they will fall to be considered as compounds, consisting of simple substances, perhaps metallic, oxydated to a certain degree. This is only hazarded as a probable conjecture: and I trust the reader will

take care not to confound what I have related as truths, fixed on the firm basis of observation and experiment, with mere hypothetical speculations.

The fixed alkalies, potash, and soda, are omitted in the foregoing Table, because they are evidently compound substances\*; though we are ignorant as yet what are the elements they are composed of.

\* For the same reason, Calca, Magnesia, and Baryta, ought to have been omitted in this edition, as has been explained in p. 219. But, though the translator has taken the freedom to make several observations and some additions, he has not ventured to make any alterations. The latter is the exclusive province of the author.—T.

## TABLE of compound or oxydable and acidifiable bases.

<i>Names of the Radicals.</i>	
Oxydable or acidifiable bases, from the mineral kingdom.	Nitro muriatic radical,* or base of the acid formerly called aqua regia.
	Tartarous radical or base.
Oxydable or acidifiable hydro-carbonous or carbon-o-hydrous radicals, from the vegetable kingdom.	Malic
	Citric
	Pyro-lignous
	Pyro-mucous
	Pyro-tartarous
	Oxalic
	Acetous
	Succinic
	Benzoic
	Camphoric
Oxydable or acidifiable radicals from the animal kingdom, which mostly contain azot, and frequently phosphorus.	Gallic
	Lactic
	Saccholactic
	Formic
	Bombic
	Sebacic
	Lithic
	Prussic.
Radicals.	

*Note.*—The Radicals from the vegetable kingdom are converted by a first degree of oxygenation into vegetable oxyds, such as sugar, starch, and gum or mucus: those of the animal kingdom by the same means form animal oxyds, as lymph, &c.—A.

\* This, for the present, may be named Azo-muria, until the radical of muriatic acid be discovered; or, at least, till the discovery of hydrogen being that radical be unquestionably ascertained.—T.

SECT. II.—*Observations upon the Table of Compound Radicals.*

The older chemists being unacquainted with the composition of acids, and not suspecting them to be formed by a peculiar radical or base for each, united to an acidifying principle or element common to all, could not consequently give any name to substances of which they had not the most distant idea. We had, therefore, to invent a new nomenclature for this subject, though we were at the same time sensible that this nomenclature must be susceptible of great modification, when the nature of the compound radicals shall become better understood \*.

The compound oxydable and acidifiable radicals from the vegetable and animal kingdoms, enumerated in the foregoing table, are not hitherto reducible to systematic nomenclature; because their exact analysis is as yet unknown. We only know in general, by some experiments of my own, and some made by Mr Hassenfratz, that most of the vegetable acids, such as the tartarous, oxalic, citric, malic, acetous, pyro-tartarous, and pyro-mucous, have radicals composed of hydrogen and carbon, combined in

\* See Part I. Chap. XI. upon this subject.—A.

such a way as to form single bases; and that these acids only differ from each other by the proportions in which these two substances enter into the composition of their bases, and by the degrees of oxygenation which these bases have received. We know farther, chiefly from the experiments of Mr Berthollet, that the radicals from the animal kingdom, and even some of those from vegetables, are of a more compound nature; and, besides hydrogen and carbon, that they often contain azot, and sometimes phosphorus. But we are not hitherto possessed of sufficiently accurate experiments for calculating the proportions of these several substances. We are therefore forced, in the manner of the older chemists, still to name these acids after the substances from which they are procured. There can be little doubt, that these names will be laid aside, when our knowledge of these substances becomes more accurate and extensive; the terms, *hydro-carbonous*, *hydro-carbonic*, *carbono-hydrous*, and *carbono-hydric*,\* will then become substituted for those we now employ, which will then only remain as testimonies of the imperfect state in which this part of chemistry was transmitted to us by our predecessors.

\* See Part I. Chap. XI. upon the application of these names according to the proportions of the two ingredients.  
—A.

It is evident, that the oils, being composed of hydrogen and carbon combined, are true carbon-hydrous or hydro-carbonous radicals : and, indeed, by adding oxygen, they are convertible into vegetable acids and oxyds, according to their degrees of oxygenation. We cannot, however, affirm, that oils enter in their entire state into the composition of vegetable oxyds and acids. It is possible, that they previously lose a part either of their hydrogen and carbon ; and that the remaining ingredients no longer exist in the proportions necessary to constitute oils. We still require farther experiments to elucidate these points.

Properly speaking, we are only acquainted with one compound radical from the mineral kingdom, the nitro-muriatic, which is formed by the combination of azot with the muriatic radical. The other compound mineral acids have been much less attended to, from their producing less striking phenomena.

SECT. III.—*Observations upon the combination of Light and Caloric with different Substances.*

I have not constructed any table of the combinations of light and caloric with the various simple and compound substances ; because our



conceptions of the nature of these combinations are not hitherto sufficiently accurate. We know in general, that all bodies in nature are imbued, surrounded, and penetrated in every way with caloric, which fills up every interval left between their particles; that, in certain cases, caloric becomes fixed in bodies, so as to constitute a part even of their solid substance; though it more frequently acts upon them with a repulsive force, from which, or from its accumulation in bodies to a greater or lesser degree, the transformation of solids into fluids, and of fluids to æriform elasticity, is entirely owing. We have employed the generic name *gas* to indicate this æriform state of bodies, produced by a sufficient accumulation of caloric; so that, when we wish to express the æriform state of muriatic acid, carbonic acid, hydrogen, water, alkohol, &c. we do it by adding the word *gas* to their names; thus muriatic acid gas, carbonic acid gas, hydrogen gas, aqueous gas, alkohol gas, &c.

The combinations of light, and its mode of acting upon different bodies, are still less known than those of caloric. By the experiments of Mr Berthollet, it appears to have great affinity with oxygen, is susceptible of combining with it, and contributes with caloric to change it into the state of gas. Experiments upon vegetation give reason to believe, that light com-

bines with certain parts of vegetables ; and that the green of their leaves, and the various colours of their flowers, are chiefly owing to this combination. This much is certain, that plants which grow in darkness, are perfectly white, languid, and unhealthy ; and that to make them recover vigour, and to acquire their natural colours, the direct influence of light is absolutely necessary. Somewhat similar takes place even upon animals. Mankind degenerate to a certain degree when employed in sedentary manufactures, or from living in crowded houses, or in the narrow lanes of large cities ; whereas they improve in their nature and constitution in most of the country labours which are carried on in the open air.

Organization, sensation, spontaneous motion, and all the operations of life, only exist at the surface of the earth, and in places exposed to the influence of light. Without it nature itself would be lifeless and inanimate. By means of light, the benevolence of the Deity hath filled the surface of the earth with organization, sensation, and intelligence. The fable of Prometheus might perhaps be considered as giving a hint of this philosophical truth, which had even presented itself to the knowledge of the ancients.

I have intentionally avoided any disquisitions relative to organized bodies in this work, for

TABLE of the Binary Combinations of Oxygen with simple Substances.

	Names of the Simple Substances.	First degree of oxygenation.		Second degree of oxygenation.		Third degree of oxygenation.		Fourth degree of oxygenation.	
		New Names.	Old Names.	New Names.	Old Names.	New Names.	Old Names.	New Names.	Old Names.
Combinations of oxygen with simple non-metallic substances.	Caloric -	Oxygen gas -	Vital or dephlogisticated air -						
	Hydrogen	Water *.							
	Azot -	Nitrous oxyd, or base of nitrous gas -	Nitrous gas or air -	Nitrous acid -	Smoking nitrous acid	Nitric acid -	Pale, or not smoking nitrous acid	Oxygenated nitric acid -	Unknown
	Carbon -	Oxyd of carbon, or carbonic oxyd -	Unknown -	Carbonous acid -	Unknown	Carbonic acid -	Fixed air -	Oxygenated carbonic acid	Unknown
	Sulphur	Oxyd of sulphur -	Soft sulphur	Sulphurous acid -	Sulphureous acid -	Sulphuric acid -	Vitriolic acid -	Oxygenated sulphuric acid	Unknown
	Phosphorus	Oxyd of phosphorus	Residuum from the combustion of phosphorus	Phosphorous acid -	Volatile acid of phosphorus	Phosphoric acid	Phosphoric acid	Oxygenated phosphoric acid	Unknown
	Muriatic radical	Muriatic oxyd -	Unknown -	Muriatous acid -	Unknown -	Muriatic acid -	Marine acid -	Oxygenated muriatic acid	Dephlogisticated marine acid
	Fluoric radical	Fluoric oxyd -	Unknown -	Fluorous acid -	Unknown -	Fluoric acid -	Unknown till lately		
	Boracic radical	Boracic oxyd -	Unknown -	Boracous acid -	Unknown -	Boracic acid -	Homburg's sedative salt		
	Antimony	Grey oxyd of antimony	Grey calx of antimony	White oxyd of antimony	White calx of antimony, diaphoretic antimony	Antimonic acid			
Combinations of oxygen with the simple metallic substances†.	Silver -	Oxyd of silver -	Calx of silver -			Argentiac acid -			
	Arsenic -	Grey oxyd of arsenic -	Grey calx of arsenic -	White oxyd of arsenic	White calx of arsenic	Arseniac acid -	Acid of arsenic -	Oxygenated arseniac acid	Unknown
	Bismuth -	Grey oxyd of bismuth	Grey calx of bismuth	White oxyd of bismuth	White calx of bismuth	Bismuthic acid -			
	Cobalt -	Grey oxyd of cobalt -	Grey calx of cobalt -			Cobaltic acid -			
	Copper	Brown oxyd of copper	Brown calx of copper	Blue and green oxyds of copper	Blue and green calces of copper	Cupric acid -			
	Tin -	Grey oxyd of tin	Grey calx of tin -	White oxyd of tin	White calx of tin, or putty of tin	Stannic acid -			
	Iron	Black oxyd of iron -	Martial ethiops -	Yellow and red oxyds of iron	Ochre and rust of iron	Ferric acid -			
	Manganese	Black oxyd of manganese	Black calx of manganese	White oxyd of manganese	White calx of manganese	Manganic acid			
	Mercury	Black oxyd of Mercury	Ethiops mineral † -	Yellow and red oxyds of mercury	Turbith mineral, red precipitate, calcined mercury, precipitate <i>per se</i>	Mercuric acid			
	Molybdena	Oxyd of molybdena -	Calx of molybdena -			Molybdic acid -	Acid of molybdena	Oxygenated molybdic acid	Unknown
	Nickel -	Oxyd of Nickel -	Calx of nickel -			Nickolic acid -			
	Gold -	Yellow oxyd of gold -	Yellow calx of gold -	Red oxyd of gold -	Red calx of gold, purple precipitate of Cassius.	Auric acid -			
	Platina -	Yellow oxyd of platina	Yellow calx of platina			Platinic acid -			
	Lead -	Grey oxyd of lead -	Grey calx of lead -	Yellow and red oxyds of lead	Mafficot and minium	Plumbic acid -			
	Tungstein	Oxyd of Tungstein -	Calx of tungstein -			Tungstic acid -	Acid of tungstein	Oxygenated tungstic acid	Unknown
	Zinc -	Grey oxyd of zinc -	Grey calx of zinc -	White oxyd of zinc -	White calx of zinc, pompholix	Zincic acid -			

\* Only one degree of oxygenation of hydrogen is hitherto known—A.

† As all the metals, in the oxyd state, are capable of acting in combinations in a similar manner with alkalies and earths, and as the last, though discovered to be compounds, are in the new nomenclature, denominated by feminine Latin terms, it would be very convenient to distinguish the oxyd state of each metal in general, from its reguline state, simply by changing the gender; thus Antimonium is the simple or reguline state, and Antimonia might indicate the oxyd state in general; any farther distinction of the oxyds may be formed as in the table. This proposed alteration is in perfect conformity with the principles of the new nomenclature, and would shorten language without introducing any ambiguity of expression.—T.

‡ Ethiops mineral is the black sulphuret of mercury; this should have been called, for the old name, black precipitate of mercury.—T





which reason the phenomena of respiration, sanguification, and animal heat, are not considered. But I hope, at some future time, to be able to elucidate these curious subjects.

SECT. IV.—*Observations upon the Combinations of Oxygen with the simple Substances.*

Oxygen forms almost a third part of the mass of our atmosphere; and is consequently one of the most plentiful substances in nature. All animals and vegetables live and grow in this immense magazine of oxygen gas: and from it we procure the greatest part of what we employ in experiments. So great is the reciprocal affinity between this element and other substances, that we cannot procure it entirely disengaged from combination. In the atmosphere, it is united with caloric, in the state of oxygen gas: and this again is mixed with about twice its weight of azotic gas.

Several conditions are requisite to enable a body to become oxygenated, or to permit oxygen to enter into combination with it. In the first place, it is necessary that the particles of the body to be oxygenated shall have less reciprocal attraction with each other, than they have for the oxygen, which otherwise cannot possibly combine with them. Nature, in this case, may be assisted by art; as we have it in our

power to diminish the attraction of the particles of bodies, almost at will, by heating them, or, in other words, by introducing caloric into the interstices between their particles: and, as the attraction of these particles for each other is diminished in the inverse ratio of their distance, it is evident, that there must be a certain point of distance of particles when the affinity they possess with each other becomes less than that they have for oxygen, and at which oxygenation must necessarily take place, if oxygen be present.

We can readily conceive, that the degree of heat at which this phenomenon begins, must be different in different bodies. Hence, on purpose to oxygenate most bodies, especially the greater part of the simple substances, it is only necessary to expose them to the influence of the air of the atmosphere, in a convenient degree of temperature. With respect to lead, mercury, and tin, this requires to be but a little higher than the medium temperature of the earth. But it requires a more considerable degree of heat to oxygenate iron, copper, &c. by the dry way, or when this operation is not assisted by moisture. Sometimes oxygenation takes place with great rapidity, and is accompanied by great sensible heat, light, and flame; such is the combustion of phosphorus in atmospheric air, and of iron in oxygen gas. That of sulphur is less



rapid : and the oxygenation of lead, tin, and most of the metals, takes place vastly slower, and consequently the disengagement of caloric, and more especially of light, is hardly sensible.

Some substances have so strong an affinity for oxygen, and combine with it in such low degrees of temperature, that we cannot procure them in their unoxygenated state ; such is the muriatic acid, which has not hitherto been decomposed by art \*, perhaps even not by nature, and which consequently has only been found in the state of acid. It is probable that many other substances of the mineral kingdom are necessarily oxygenated in the common temperature of the atmosphere ; and that, being already saturated with oxygen, their farther action upon that element is thereby prevented.

There are other means of oxygenating simple substances, besides exposure to air in a certain degree of temperature ; such as by placing them in contact with metals combined with oxygen, and which have little affinity with that element. The red oxyd of mercury is one of the best substances for this purpose, especially with bodies which do not combine with that metal. In this oxyd, the oxygen is united with very little force

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\* The real or supposed discovery of the base of this acid has been mentioned in some former notes.—T.

to the metal, and can be driven out by a degree of heat only sufficient to make glass red hot : wherefore, such bodies as are capable of uniting with oxygen, are readily oxygenated, by means of being mixed with red oxyd of mercury, and then moderately heated. The same effect may be, to a certain degree, produced by means of the black oxyd of manganese, the red oxyd of lead, the oxyds of silver, and by most of the metallic oxyds, if we only take care to choose such as have less affinity with oxygen than the bodies they are meant to oxygenate ; all the metallic reductions and revivifications belong to this class of operations, being nothing more than oxygenations of carbon, by means of the several metallic oxyds. The carbon of the charcoal employed for this reduction, combines with the oxygen and with caloric, and escapes in form of carbonic acid gas ; while the metal remains pure and revivified, or deprived of the oxygen which before combined with it in the form of oxyd.

All combustible substances may likewise be oxygenated by means of mixing them with nitrat of potash or of soda, or with oxygenated muriat of potash, and subjecting the mixture to a certain degree of heat. The oxygen, in this case, quits the nitrat or the muriat, and combines with the combustible body. This species of oxygenation requires to be performed with

extreme caution, and only with very small quantities; because, as the oxygen enters into the composition of nitrats, and more especially of oxygenated muriats, combined with almost as much caloric as is necessary for converting it, into oxygen gas, this immense quantity of caloric becomes suddenly free, the instant of the combination of the oxygen with the combustible body, and produces such violent explosions as are perfectly irresistible.

By the humid way we can oxygenate most combustible bodies, and convert most of the oxyds of the three kingdoms of nature into acids. For this purpose we chiefly employ the nitric acid, which has a very slight hold of oxygen, and quits it readily to a great number of bodies, by the assistance of a gentle heat. The oxygenated muriatic acid may be used for several operations of this kind, but not in them all.

I give the name of *binary* to the combinations of oxygen with the simple substances, because in these only two elements are combined. When three substances are united in one combination I call it *ternary*; and *quaternary* when the combination consists of four substances united.

TABLE of the Combinations of Oxygen with the  
Compound Radicals.

<i>Names of the Radicals.</i>	<i>Names of the resulting Acids.</i>	
	<i>New Nomenclature.</i>	<i>Old Nomenclature.</i>
Nitro-muriatic radical	}	Nitro-muriaticacid
		Aqua regia.
*		
Tartaric	Tartarous acid	Unknown till lately.
Malic	Malic acid	Ditto.
Citric	Citric acid	Acid of lemons.
Pyro-lignous	Pyro-lignous acid	{ Empyreumatic acid of wood.
Pyro-mucous	Pyro-mucous acid	
Pyro-tartarous	Pyro-tartarous acid	Empyr. acid of sug.
Oxalic	Oxalic acid	Empyr. acid of tartr.
		Acid of forrel.
Acetic	{ Acetous acid	{ Vinegar, or acid of vinegar.
	{ Acetic acid	Radical vinegar.
Succinic	Succinic acid	Volatile salt of amber
Benzoic	Benzoic acid	Flowers of Benzoin.
Camphoric	Camphoric acid	Unknown till lately.
Gallic	Gallic acid	{ The astringent
		{ prin. of vege.
**		
Lactic	Lactic acid	Acid of four whey.
Saccholactic	Saccholactic acid	Unknown till lately.
Formic	Formic acid	Acid of ants.
Bombic	Bombic acid	Unknown till lately.
Sebacic	Sebacic acid	Ditto.
Lithic	Lithic acid	Urinary calculus.
Prussic	Prussic acid	{ Colouring matter
		{ of Prussian blue.

\* These radicals by a first degree of oxygenation form vegetable oxyds, as sugar, starch, mucus, &c.—A.

\*\* These radicals by a first degree of oxygenation form the animal oxyds, as lymph, and part of the blood, animal secretions, &c.—A.

SECT. V.—*Observations upon the Combinations of Oxygen with the Compound Radicals.*

I published a new theory of the nature and formation of acids in the Memoirs of the Academy for 1776, p. 671. and 1778, p. 535, in which I concluded, that the number of acids must be greatly larger than was till then supposed. Since that time, a new field of inquiry has been opened to chemists: and, instead of five or six acids, which were then known, near thirty new acids have been discovered, by which means the number of known neutral salts has been increased in the same proportion. The nature of the acidifiable bases, or radicals of the acids, and the degrees of oxygenation they are susceptible of, still remain to be inquired into. I have already shown, that almost all the oxydable and acidifiable radicals from the mineral kingdom are simple; that, on the contrary, there hardly exists any radical in the vegetable, and more especially in the animal kingdom, but is composed of at least two substances, hydrogen and carbon; and that azot and phosphorus are frequently united to these, by which we have compound radicals of two, three, and four bases or simple elements united.



From these observations, it appears, that the vegetable and animal oxyds and acids may differ from each other in three several ways; according to the number of simple acidifiable elements of which their radicals are composed; according to the proportions in which these are combined together; and according to their different degrees of oxygenation. These circumstances are more than sufficient to explain the great variety which nature produces in these substances. It is not at all surprizing, after this, that most of the vegetable acids are convertible into each other; nothing more being requisite for this purpose, than to change the proportions of the hydrogen and carbon in their composition, and to oxygenate them in a greater or lesser degree. This has been done by Mr Crell in some very ingenious experiments, which have been verified and extended by Mr Haffenratz. From these it appears, that carbon and hydrogen, by a first oxygenation, produce tartarous acid, oxalic acid by a second degree, and acetous or acetic acid by a third, or higher oxygenation; only, that carbon seems to exist in a rather smaller proportion in the acetous and acetic acids. The citric and malic acids differ little from the preceding acids.

Ought we then to conclude, that the oils are the radicals of the vegetable and animal acids? I have already expressed my doubts upon this



subject: For, although the oils appear to be formed of nothing but hydrogen and carbon, we do not know if these are in the precise proportion necessary for constituting the radicals of the acids; and, since oxygen enters into the composition of these acids equally with hydrogen and carbon, there is no more reason for supposing them to be composed of oil rather than of water or of carbonic acid. It is true that they contain the materials necessary for all these combinations; but then these do not take place in the common temperature of the atmosphere. All the three elements remain combined in a state of equilibrium, which is readily destroyed by a temperature only a little above that of boiling water \*.

\* See part I. Chap. XII. upon this subject.—A.

TABLE of the Binary Combinations of Azot with the Simple Substances.

Simple Substances.	Results of the Combinations.	
	New Nomenclature.	Old Nomenclature.
Caloric	Azotic gas, or Azogas	{ Phlogisticated air, or Mephitic.
Hydrogen	Ammoniac, Ammona	Volatile alkali.
Oxygen	{ Nitrous oxyd	Base of nitrous gas.
	{ Nitrous acid	Smoking nitrous acid.
	{ Nitric acid	Pale nitrous acid.
	{ Oxygenated nitric acid.	Unknown.
Carbon	{ This combination is hitherto unknown.	
	{ Should it ever be discovered, it will be called, according to the principles of our nomenclature, Azuret of Carbon. Carbon dissolves in azotic gas, and forms carbonated azotic gas.	
Phosphorus	Azuret of phosphorus.	Still unknown.
Sulphur	{ Azuret of Sulphur.	Still unknown. We know that sulphur dissolves in azotic gas, forming sulphurated azotic gas.
	{ Azot combines with carbon and hydrogen, and sometimes with phosphorus, in the compound oxydable and acidifiable bases; and is generally contained in the radicals of the animal acids.	
Compound radicals	{	
Metallic substances.	{ Such combinations are hitherto unknown.	
	{ If ever discovered, they will form metallic azurets, as azuret of gold, of silver, &c.	
Lime	{	Entirely unknown: If ever discovered, they will form azuret of lime, azuret of magnesia, &c.
Magnesia		
Barytes		
Argill		
Potash		
Soda		

*Note.* The Latin term, in the new nomenclature, here translated Azuret, is *Azuretum*. The French of Mr. Lavoisier is Azure. I preferred taking the English from the Latin, be-

SECT. VI.—*Observations upon the Combinations of Azot with the Simple Substances.*

AZOT is one of the most abundant elements ; combined with caloric it forms azotic gas, or mephitic, which composes nearly two-thirds of the atmosphere. This element is always in the state of gas in the ordinary pressure and temperature, and no degree of compression or of cold has been hitherto capable of reducing it either to a solid or liquid form. This is likewise one of the essential constituent elements of animal bodies in which it is combined with carbon and hydrogen; and sometimes with phosphorus ; these are united together along with a certain portion of oxygen, by which they are formed into oxyds or acids, according to the degree of oxygenation. Hence the animal substances may be varied, in the same way with vegetables, in three different manners ; according to the number of elements which enter into the compo-

cause it is thus more distinct from other terms : the French terms Azure, Sulphure, Phosphure, are not sufficiently distinguishable in English, from Azure, a colour, Sulphur, and Phosphor, which is sometimes used for Phosphorus ; but Azuret, Sulphuret, Carburet, and Phosphuret, which are translated from Azuretum, Sulphuretum, Carburetum, and Phosphoretum, both answer the purpose of the new nomenclature completely, and run no hazard of occasioning any mistake.—T.

tion of the base or radical; according to the proportion of these elements; and, according to the degrees of oxygenation.

When combined with oxygen, azot forms the nitrous and nitric oxyds and acids; when with hydrogen, ammoniac is produced. Its combinations with the other simple elements are very little known; to these we give the name of Azurets, preserving the termination in *uret* for all unoxxygenated compounds. It is extremely probable that all the alkaline substances may hereafter be found to belong to this genus of azurets.

The azotic gas may be procured from atmospheric air, by absorbing the oxygen gas which is mixed with it by means of a solution of sulphuret of potash, or sulphuret of lime. It requires twelve or fifteen days to complete this process, during which time the surface in contact must be frequently renewed by agitation, and by breaking the pellicle which forms on the top of the solution. It may likewise be procured by dissolving animal substances in dilute nitric acid very little heated. In this operation the azot is disengaged in form of gas, which must be received under bell-glasses filled with water, in the pneumatological apparatus. We may procure this gas by deflagrating nitre with charcoal, or any other combustible substance; when with charcoal, the azotic gas is

mixed with carbonic acid gas, which may be absorbed by a solution of caustic alkali, or by lime water; after which the azotic gas remains pure. We can procure it in a fourth manner from combinations of ammoniac with metallic oxyds, as pointed out by Mr de Fourcroy. The hydrogen of the ammoniac combines with the oxygen of the oxyd, and forms water; while the azot being left free escapes in form of gas.

The combinations of azot were but lately discovered. Mr Cavendish first observed it in nitrous gas and acid, and Mr Berthollet in ammoniac and the prussic acid. As no evidence of its decomposition has hitherto appeared, we are fully entitled to consider azot as a simple elementary substance.

TABLE of the Binary Combinations of Hydrogen  
with Simple Substances.

<i>Simple Substances.</i>	<i>Resulting Compounds.</i>	
	<i>New Nomenclature.</i>	<i>Old Names.</i>
Caloric	Hydrogen gas	Inflammable air.
Azot	Ammoniac	Volatile alkali.
Oxygen	Water	Water.
Sulphur	{ Hydruret of Sulphur, or sulphuret of hydrogen }	Hitherto un- known. *
Phosphorus	{ Hydruret of phosphorus or phosphuret of hydrogen }	
Carbon	{ Hydro-carbonous, or car- bona-hydrous radicals † }	Not known till lately.
Metallic sub- stances, as iron, &c.	{ Metallic hydrurets ‡, as hydruret of iron, &c. }	
		Hitherto un- known.

\* These combinations take place in the state of gas, and form, respectively, sulphurated and phosphorated hydrogen gas.—A.

† This combination of hydrogen with carbon includes the fixed and volatile oils, and forms the radicals of a considerable part of the vegetable and animal oxyds and acids. When it takes place in the state of gas, it forms carbonated hydrogen gas.—A.

‡ None of these combinations are known, and it is probable that they cannot exist, at least in the usual temperature of the atmosphere, owing to the great affinity of hydrogen for caloric.—A.



SECT. VII.—*Observations upon Hydrogen, and its Combinations with Simple Substances.*

Hydrogen, as its name expresses, is one of the constituent elements of water, of which it forms fifteen-hundredth parts by weight, combined with eighty-five hundredth-parts of oxygen. This substance, the properties and even existence of which was unknown till lately, is very plentifully distributed in nature, and acts a very considerable part in the processes of the animal and vegetable kingdoms. As it possesses so great affinity with caloric as only to exist in the state of gas, it is consequently impossible to procure it in the concrete or liquid state, independent of combination.

To procure hydrogen, or rather hydrogen gas, we have only to subject water to the action of a substance with which oxygen has a greater affinity than it has to hydrogen; by this means the hydrogen is set free, and, by uniting with caloric, assumes the form of hydrogen gas. Red hot iron is usually employed for this purpose: The iron, during the process, becomes oxydized, and is changed into a substance resembling the iron ore from the island of Elba. In this state of oxyd it is much less attractible by

the magnet, and dissolves in acids without effervescence.

Charcoal, in a red heat, has the same power of decomposing water, by attracting the oxygen from its combination with hydrogen. In this process carbonic acid gas is formed, and mixes with the hydrogen gas, but is easily separated by means of water or alkalies, which absorb the carbonic acid, and leave the hydrogen gas pure. We may likewise obtain hydrogen gas by dissolving iron or zinc in dilute sulphuric acid. The two metals decompose water very slowly, and with great difficulty, when alone, but do it with great ease and rapidity when assisted by sulphuric acid; the hydrogen unites with caloric during the process, and is disengaged in form of hydrogen gas, while the oxygen of the water unites with the metal in the form of oxyd, which is immediately dissolved in the acid, forming a sulphat of iron or of zinc.

Some very distinguished chemists consider hydrogen as the *phlogiston* of Stahl; and as that celebrated chemist admitted the existence of phlogiston in sulphur, charcoal, metals, &c. they are of course obliged to suppose that hydrogen exists in all these substances, though they cannot prove their supposition; even if they could, it would not avail much, since this disengagement of hydrogen is quite insufficient to explain the phenomena of calcination and combustion.

We must always recur to the examination of this question, “Are the heat and light, which are disengaged during the different species of combustion, furnished by the burning body, or by the oxygen which combines in all these operations?” And certainly the supposition of hydrogen being disengaged throws no light whatever upon this question. Besides, it belongs to those who make suppositions, to prove them; and, doubtless, a doctrine which without any supposition explains the phenomena as well, and as naturally, as theirs does by supposition, has at least the advantage of greater simplicity\*.

\* Those who wish to see what has been said upon this great chemical question by Mess. de Morveau, Berthollet, De Fourcroy, and myself, may consult our translation of Mr. Kirwan’s Essay on Phlogiston.—A.

TABLE of the Binary Combinations of Sulphur with Simple Substances.

Simple Substances.	Resulting Compounds.	
	New Nomenclature.	Old Nomenclature.
Caloric	Sulphuric gas	
Oxygen	{ Oxyd of sulphur	Soft sulphur.
	{ Sulphurous acid	Sulphureous acid.
	{ Sulphuric acid	Vitriolic acid.
Hydrogen	Sulphuret of hydrogen	{ Unknown Combinations.
Azot	azot	
Phosphorus	phosphorus	
Carbon	carbon	
Antimony	antimony	Crude antimony.
Silver	silver	Orpiment realgar.
Arsenic	arsenic	
Bismuth	bismuth	
Cobalt	cobalt	Copper pyrites.
Copper	copper	
Tin	tin	Iron pyrites.
Iron	iron	
Manganese	manganese	{ Ethiops mineral, cinnabar.
Mercury	mercury	
Molybdena	molybdena	Galena.
Nickel	nickel	
Gold	gold	
Platina	platina	
Lead	lead	
Tungstein	tungstein	Blende.
Zinc	zinc	
Potash	potash	{ Alkaline liver of sulphur with fixed veget. alkali.
Soda	soda	{ Alkaline liver of sulphur with fixed mineral alkali.
		{ Volatile liver of sulphur, smoaking liquor of Boyle.
Ammoniac	ammoniac	{ Calcareous liver of sulphur.
Lime	lime	{ Magnesian liver of sulphur.
Magnesia	magnesia	{ Barytic liver of sulphur.
Barytes	barytes	{ Yet unknown.
Argill	argill	

SECT. VIII.—*Observations on Sulphur and its Combinations.*

Sulphur is a combustible substance, having a very great tendency to combination; it is naturally in a solid state in the ordinary temperature, and requires a heat somewhat higher than that of boiling water to make it liquefy. Sulphur is formed by nature in a considerable degree of purity in the neighbourhood of volcanos; we find it, likewise, chiefly in the state of fulphuric acid, combined with argill in aluminous schistus, with lime in gypsum, &c. From these combinations it may be procured in the state of sulphur, by carrying off its oxygen by means of charcoal in a red heat; carbonic acid is formed, and escapes in the state of gas; the sulphur remains combined with the clay, lime, &c. in the state of sulphuret, which is decomposed by acids; the acid unites with the earth into a neutral salt, and the sulphur is precipitated.

TABLE of the Binary Combinations of Phosphorus  
with the Simple Substances.

Simple Substances.			Resulting Compounds.
Caloric	-	-	Phosphoric gas.
Oxygen	-	-	{ Oxyd of phosphorus. Phosphorous acid. Phosphoric acid.
Hydrogen	-	-	Phosphuretof hydrogen.
Azot	-	-	Phosphuret of azot.
Sulphur	-	-	Phosphuret of Sulphur.
Carbon	-	-	Phosphuret of carbon.
Metallic Substances			Phosphurets of metals.*
Potash	-	-	{ Phosphuret of Potash, Soda, &c. †
Soda	-	-	
Ammoniac	-	-	
Lime	-	-	
Barytes	-	-	
Magnesia	-	-	
Argill	-	-	

\* Of all these combinations of phosphorus with metals, that with iron only is hitherto known, forming the substance formerly called Siderite; neither is it yet ascertained whether, in this combination, the phosphorus be oxygenated or not.—A.

† These combinations of phosphorus with the alkalies and earths are not yet known; and, from the experiments of Mr Gengembre, they appear to be impossible.—A.



SECT. IX.—*Observations on Phosphorus, and its Combinations.*

Phosphorus is a simple combustible substance, which was unknown to chemists till 1667, when it was discovered by Brandt, who kept the process secret; soon after Kunkel found out Brandt's method of preparation, and made it public. It has been ever since known by the name of Kunkel's phosphorus. It was for a long time procured only from urine; and, though Homberg gave an account of the process in the Memoirs of the academy for 1692, all the philosophers of Europe were supplied with it from England. It was first made in France in 1737, before a committee of the academy at the Royal Garden. At present it is procured in a more commodious and more economical manner from animal bones, which are real calcareous phosphates, according to the processes of Messrs Gahn, Scheele, Rouelle, &c. The bones of adult animals, being calcined to whiteness, are pounded, and passed through a fine silk sieve; upon the fine powder a quantity of dilute sulphuric acid is poured, less than is sufficient for dissolving the whole. This acid unites with the calcareous earth of the bones into a sulphate of lime, and the phosphoric acid remains free in the liquor. The liquid

is decanted off, and the residuum washed with boiling water; this water which has been used to wash out the adhering acid, is joined with what was before decanted off, and the whole is gradually evaporated; the dissolved sulphat of lime crystallizes in form of silky threads, which are removed; and, by continuing the evaporation, we procure the phosphoric acid, under the appearance of a white pellucid glass. When this is powdered, and mixed with one third its weight of charcoal, we procure very pure phosphorus, by sublimation \*. The phosphoric acid, as procured by the above process, is never so pure as that obtained by oxygenating pure phosphorus, either by combustion or by means of nitric acid; wherefore this latter should always be employed in experiments of research.

Phosphorus is found in almost all animal substances, and in some plants which give a kind

\* A very convenient method of procuring phosphorus from urine has lately been discovered. The phosphoric acid is precipitated by a solution of acetite of lead, by means of a double decomposition: the lead uniting with the phosphoric acid into an insoluble salt which precipitates, while the acetous acid unites with the alkaline substances of the urine and remains dissolved. The phosphat of lead is then repeatedly washed, and is decomposed by means of muriatic acid: a muriat of lead is formed, which is insoluble, and the phosphoric acid is found in a liquid state; this is evaporated to dryness, and, being disoxygenated by charcoal, in the usual manner, a very pure phosphorus sublimes.—T.

of animal analysis. In all these it is usually combined with carbon, hydrogen, and azot, forming very compound radicals, which are, for the most part, in the state of oxyds, by a first degree of union with oxygen. The discovery of Mr Hassenfratz, of phosphorus being contained in charcoal, gives reason to suspect that it is more common in the vegetable kingdom than has generally been supposed. It is certain, that by proper processes, it may be procured from every individual of some of the families of plants. As no experiment has hitherto given reason to suspect that phosphorus is a compound body, I have arranged it with the simple or elementary substances. It takes fire at the temperature of  $104^{\circ}$  of the thermometer.

TABLE of the Binary Combinations of Carbon.

<i>Simple</i>	<i>Resulting Compounds.</i>		
<i>Substances.</i>	<i>New Nomenclature.</i>	<i>Old Names.</i>	
Oxygen	{ Oxyd of carbon Carbonic acid	Unknown. Fixed air, chalky acid.	
Sulphur	Carburet of sulphur	} Unknown.	
Phosphorus	Carburet of phosphorus		
Azot	Carburet of azot		
Hydrogen	{ Carbono-hydrous radicals Fixed with volatile oils	} Of these only the carburets of iron and zinc are known, and were formerly called Plumbago.	
Metallic sub- stances.	{ Carburets of the several metals.		
Alkalies and earths.	{ Carburet of potash, &c.		Unknown.

SECT. X.—*Observations upon Carbon, and its Combinations with Simple Substances.*

As carbon has not been hitherto decomposed, it must, in the present state of our knowledge, be considered as a simple substance. By modern experiments it appears to exist ready formed in vegetables; and I have already remarked, that, in these, it is combined with hydrogen, sometimes with azot and phosphorus, forming compound radicals, which may be changed into oxyds or acids, according to their degrees of oxygenation.

To obtain the carbon \* contained in vegetable or animal substances, we subject them to the action of fire, at first moderate, and afterwards very strong, on purpose to drive off the last portions of water, which adhere very obstinately. For chemical purposes this is usually done in retorts of stone-ware or porcelain, into which the wood, or other matter, is introduced, and then placed in a reverberatory furnace, raised gradually to its greatest heat: The heat volatilizes,

\* It is necessary to repeat, that carbon is used to denote the pure simple elementary substance, while charcoal signifies that substance, united with some small portions of earths and salts, as procured from vegetable and animal bodies by burning, or by distillation in a red heat.—T.

or changes into gas, all the parts of the body susceptible of combining with caloric into that form; and the carbon being more fixed in its nature, remains in the retort, combined with a little earth and some fixed salts, in the form generally known by the name of charcoal.

In the business of charring wood, this is done by a less expensive process. The wood is disposed in heaps regularly arranged, and covered with earth, so as to prevent the access of any more air than is absolutely necessary for supporting the fire, which is kept up till all the water and oil is driven off, after which the fire is extinguished by shutting up all the air-holes.

We may analyse charcoal either by combustion in air, or rather in oxygen gas, or by means of nitric acid: In either case we convert its pure carbon into carbonic acid; and sometimes a little potash and some neutral salts remain. This analysis has been hitherto but little attended to by chemists; and we are not even certain if potash exists in charcoal before combustion, or whether it be formed by means of some unknown combination during that process.

SECT. XI.—*Observations upon the Muriatic, Fluoric, and Boracic Radicals, and their Combinations.*

As the combinations of these substances, either with each other, or with the other combus-

tible bodies, are hitherto entirely unknown, we have not attempted to form any table for their nomenclature. We only know, that these radicals are susceptible of oxygenation, and of forming the muriatic, fluoric, and boracic acids: and that, in the acid state, they enter into a number of combinations, to be afterwards detailed. Chemistry has hitherto been unable to disoxygenate any of them, so as to exhibit them in a simple state. For this purpose, some substance must be employed, to which oxygen has a stronger affinity than to their radicals, either by means of single affinity, or by double elective attraction. All that is known relative to the origin of the radicals of these acids, will be mentioned in the sections set apart for considering their combinations with the salifiable bases.

SECT. XII.—*Observations upon the Combinations of Metals with each other.*

Before closing our account of the simple or elementary substances, it might be supposed necessary to give a table of alloys or combinations of metals with each other; but, as such a table would be both exceedingly voluminous and very unsatisfactory, without going into a series of experiments not yet attempted, I have thought it adviseable to omit it altogether. All



that is necessary to be mentioned, is, that these alloys should be named according to the metal in largest proportion in the mixture or combination ; thus the term *alloy of gold and silver*, or gold alloyed with silver, indicates that gold is the predominating metal.

Metallic alloys, like all other combinations, have a point of saturation. It would even appear, from the experiments by Mr de la Briche, that they have two perfectly distinct degrees of saturation:

N n

TABLE

*TABLE of the Combinations of Azot, in the state of Nitrous Acid, with the Salifiable Bases, arranged according to the Affinities of these Bases with the Acid.*

<i>Names of the Bases.</i>	<i>Names of the Neutral Salts. New Nomenclature.</i>	<i>Notes.</i>
Barytes	Nitrite of barytes.	<p>These salts are only known of late, and have received no particular names in the old nomenclature.</p>
Potash	potash.	
Soda	soda.	
Lime	lime.	
Magnesia	magnesia.	
Ammoniac	ammoniac.	
Argill	argill.	<p>As metals dissolve both in nitrous and nitric acids, metallic salts must of consequence be formed having different degrees of oxygenation. Those wherein the metal is least oxygenated, must be called Nitrites, and when more so, Nitrats; but the limits of this distinction are difficultly ascertainable. The older chemists were not acquainted with any of these salts.</p>
Oxyd of zinc	zinc.	
iron	iron.	
manganese	manganese.	
cobalt	cobalt.	
nickel	nickel.	
lead	lead.	
tin	tin.	
copper	copper.	
bismuth	bismuth.	
antimony	antimony.	
arsenic	arsenic.	
mercury	mercury.	
silver	<p>It is extremely probable that gold, silver and platina, only form nitrats, and cannot subsist in the state of nitrites.</p>	
gold		
platina		

TABLE

**TABLE** of the Combinations of Azot, completely saturated with Oxygen, in the state of Nitric acid, with the Salifiable Bases, in the Order of their Affinity with that Acid.

		Names of the resulting Neutral Salts.	
Bases.		New Nomenclature.	Old Nomenclature.
Barytes	Nitrat of barytes		{ Nitre, with a base of heavy earth.
Potash	potash		{ Nitre, saltpetre, Nitre with base of potash.
Soda	soda		{ Quadrangular Nitre, Nitre with base of mineral alkali.
Strontites	strontites		{ Unknown.
Lime	lime		{ Calcareous nitre. Nitre with calcareous base, Mother water of nitre, or of saltpetre.
Magnesia	magnesia		{ Magnesian nitre, Nitre with base of magnesia.
Ammoniac	ammoniac		{ Ammoniacal nitre.
Argill	argill		{ Nitrous alum, Argillaceous nitre, Nitre with base of earth of alum.
Oxyd of zinc	zinc		{ Nitre of zinc.
iron	iron		{ Nitre of iron, Martial nitre, Nitrated iron.
manganese	manganese		{ Nitre of manganese.
cobalt	cobalt		{ Nitre of cobalt.
nickel	nickel		{ Nitre of nickel.
lead	lead		{ Saturnine nitre, Nitre of lead.
tin	tin		{ Nitre of tin.
copper	copper		{ Nitre of copper, or of Venus.
bismuth	bismuth		{ Nitre of bismuth.
antimony	antimony		{ Nitre of antimony.
arsenic	arsenic		{ Arsenical nitre.
mercury	mercury		{ Mercurial Nitre.
silver	silver		{ Nitre of silver, or of luna, Lunar caustic.
gold	gold		{ Nitre of gold.
platina	platina		{ Nitre of platina.

SECT. XIII.—*Observations upon the Nitrous and Nitric Acids, and their Combinations.*

The nitrous and nitric acids are procured from a neutral salt, long known in the arts, under the name of *saltpetre*. This salt is extracted by lixiviation from the rubbish of old buildings, from the earth of cellars, stables, or barns, and in general of all inhabited places\*. In these earths, the nitric acid is usually combined with lime and magnesia, sometimes with potash, and rarely with argill. As all these salts, excepting the nitrat of potash, attract the moisture of the air, and consequently would be difficultly preserved, advantage is taken, in the manufactories of saltpetre, and in the royal refining house, of the greater affinity of the nitric acid to potash than these other bases; by which means the lime, magnesia, and argill, are precipitated, and all these nitrats are reduced to the nitrat of potash, or saltpetre.

The nitric acid is procured from this salt by means of distillation. Three parts of pure salt-

\* Saltpetre is likewise procured in large quantities by lixiviating the natural soil in some parts of Bengal, and of the Russian Ukrain.—T.

petre are decomposed by means of one part of concentrated sulphuric acid, in a retort with Woulfes' apparatus, (Pl. IV. Fig. 1.) having its bottles half filled with water, and all its joints carefully luted. The nitrous acid passes over in form of red vapours surcharged with nitrous gas, or, in other words, not completely saturated with oxygen. Part of the acid condenses in the recipient, in form of a dark orange red liquid; while the rest combines with the water in the bottles. During the distillation, a large quantity of oxygen gas escapes, owing to the greater affinity of oxygen to caloric, in a high temperature, than to nitrous acid; though in the usual temperature of the atmosphere, this affinity is reversed. It is from the disengagement of oxygen, that the nitric acid of the neutral salt is in this operation converted into nitrous acid\*. It is brought back to the state of nitric acid by heating over a gentle fire, which drives off the superabundant nitrous gas, and leaves the nitric acid much diluted with water.

\* It is evident, that in this operation, there is a very great loss of nitric acid; as, from the disengagement of oxygen, we cannot possibly procure near the same quantity of nitric acid by distillation, that existed in the combined state in the nitre.—T.

Nitric acid is procurable in a more concentrated state, and with much less loss, by mixing very dry clay with saltpetre. This mixture is put into an earthen retort, and distilled with a strong fire. The clay combines with the potash, for which it has great affinity; and the nitric acid passes over, slightly impregnated with nitrous gas. This is easily disengaged by heating the acid gently in a retort; a small quantity of nitrous gas passes over into the recipient; and very pure concentrated nitric acid remains in the retort.

We have already seen, that azot is the nitric radical. If to  $20\frac{1}{2}$  parts by weight, of azot,  $43\frac{1}{2}$  parts of oxygen be added, 64 parts of nitrous gas are formed; and if to this we join 36 additional parts of oxygen, 100 parts of nitric acid result from the combination. Intermediate quantities of oxygen, between these two extremes of oxygenation, produce different species of nitrous acid; or, in other words, nitric acid less or more impregnated with nitrous gas. I ascertained the above proportions by means of decomposition; and though I cannot answer for their absolute accuracy, they cannot be far removed from truth. Mr Cavendish, who first shewed by synthetic experiments, that azot is the base of nitric acid, gives the proportions of azot a little larger than I have done: but, as it is not improbable, that he produced the nitrous



acid, and not the nitric, that circumstance explains in some degree the difference in the results of our experiments.

As, in all experiments of a philosophical nature, the utmost possible degree of accuracy is required, we must procure the nitric acid for experimental purposes, from nitre which has been previously purified from all foreign matters. If, after distillation, any sulphuric acid is suspected in the nitric acid, it is easily separated by dropping in a little nitrat of barytes, so long as any precipitation takes place; the sulphuric acid, from its greater affinity, attracts the barytes, and forms with it an insoluble neutral salt, which falls to the bottom. It may be purified in the same manner from muriatic acid, by dropping in a little nitrat of silver, so long as any precipitation of muriat of silver is produced. When these two precipitations are finished, distil off about seven-eighths of the acid by a gentle heat, and what comes over is in the most perfect degree of purity.

The nitric acid is remarkably prone to combination, and is at the same time very easily decomposed. Almost all the simple substances, with the exception of gold, silver, and platina, rob it less or more of oxygen; some of them even decompose it altogether. It was very anciently known: and its combinations have been more studied by chemists than those of any o-

ther acid. These combinations were named *nitres* by Messrs Macquer and Beaumé: but we have changed their names to nitrats and nitrites, according as they are formed by nitric or by nitrous acid; and have added the specific name of each particular base, to distinguish the several combinations from each other.

TABLE of the Combinations of Sulphuric Acid with the Salifiable Bases, in the Order of Affinity.

Names of the Bases.		Resulting Compounds.
New Nomenclature.		Old Nomenclature.
Barytes	Sulphat of barytes	{ Heavy spar, Vitriol of heavy earth.
Strontites	strontites	{ Unknown.
Potash	potash	{ Vitriolated tartar, Sal de duobus, Arcanum duplicatum.
Soda	soda	{ Glauber's salt.
Lime	lime	{ Selenite, gypsum, calcareous vitriol.
Magnesia	magnesia	{ Epsom salt, Sedlitz salt, Magnesian vitriol.
Ammoniac	ammoniac	{ Glauber's secret sal ammoniac.
Argill	argill	{ Alum.
Oxyd of zinc	zinc	{ White vitriol, Goslar vitriol, White copperas, Vitriol of zinc.
iron	iron	{ Green copperas, Green vitriol, Martial vitriol, Vitriol of iron.
manganese	manganese	{ Vitriol of manganese.
cobalt	cobalt	{ Vitriol of cobalt.
nickel	nickel	{ Vitriol of nickel.
lead	lead	{ Vitriol of lead.
tin	tin	{ Vitriol of tin.
copper	copper	{ Blue copperas, Blue vitriol, Roman vitriol, Vitriol of copper.
bismuth	bismuth	{ Vitriol of bismuth.
antimony	antimony	{ Vitriol of antimony.
arsenic	arsenic	{ Vitriol of arsenic.
mercury	mercury	{ Vitriol of mercury.
silver	silver	{ Vitriol of silver.
gold	gold	{ Vitriol of gold.
platina	platina	{ Vitriol of platina.

SECT. XIV.—*Observations upon Sulphuric Acid, and its Combinations.*

For a long time, this acid was procured by distillation from sulphat of iron, in which sulphuric acid and oxyd of iron are combined, according to the process described by Basil Valentine in the fifteenth century; but, in modern times, it is procured more economically by the combustion of sulphur in proper vessels. Both to facilitate the combustion, and to assist the oxygenation of the sulphur, a little powdered saltpetre, or nitrat of potash, is mixed with it; the nitre is decomposed, giving out its oxygen to the sulphur, and contributes to its conversion into an acid. Notwithstanding this addition, the sulphur will only continue to burn, in close vessels, for a limited time; the combination soon ceases, because the oxygen is exhausted, and the air of the vessels is reduced almost to pure azotic gas; and because the acid itself remains long in the state of vapour, and hinders the progress of combustion.

In the manufactories for making sulphuric acid in the large way, the mixture of nitre and sulphur is burnt in large close-built chambers, lined with lead, having a little water at the bottom, for facilitating the condensation of the vapours. Afterwards, by distillation in large re-

torts with a gentle heat, the water passes over, slightly impregnated with acid, and the sulphuric acid remains behind in a concentrated state. It is then pellucid, without any flavour, and nearly double the weight of an equal bulk of water. This process would be greatly facilitated, and the combustion much prolonged, by introducing fresh air into the chambers, by means of several pairs of bellows, directed towards the flame of the sulphur, and by allowing the nitrous gas to escape through long serpentine canals, in contact with water, to absorb any sulphuric or sulphurous acid gas it might contain.

By one experiment, Mr Berthollet found that 69 parts of sulphur in combustion, united with 31 parts of oxygen, to form 100 parts of sulphuric acid : and, by another experiment, made in a different manner, he calculates that 100 parts of sulphuric acid consist of 72 parts of sulphur, combined with 28 parts of oxygen, all by weight.

This acid, in common with every other, can only dissolve metals when they have been previously oxydated : but most of the metals are capable of decomposing a part of the acid, so as to carry off a sufficient quantity of oxygen, to render themselves soluble in the part of the acid which remains undecomposed. This happens with silver, mercury, iron, and zinc, in boiling concentrated sulphuric acid ; they be-

come first oxydated by decomposing part of the acid, and are then dissolved in the other part. But they do not sufficiently disoxygenate the decomposed part of the acid, to reconvert it into sulphur. It is only reduced to the state of sulphurous acid, which, being volatilised by the heat, flies off in the form of sulphurous acid gas.

Silver, mercury, and all the other metals, except iron and zinc, are insoluble in diluted sulphuric acid, because they have not sufficient affinity with oxygen to withdraw it from its combination either with the sulphur, the sulphurous acid, or the hydrogen; but iron and zinc, being assisted by the action of the acid, decompose the water, and become oxydated at its expense, without the help of heat.



TABLE of the Combinations of the Sulphurous Acid with the Salifiable Bases, in the Order of Affinity.

<i>Names of the Bases.</i>	<i>Names of the Neutral Salts.</i>
Barytes	Sulphite of barytes.
Potash	potash.
Soda	soda.
Lime	lime.
Magnesia	magnesia.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
tin	tin.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic.
mercury	mercury.
silver	silver.
gold	gold.
platina	platina.

*Note.*—The only one of these salts known to the old chemists was the sulphite of potash, under the name of *Stahl's sulphureous salt*: So that, before our new nomenclature, these compounds must have been named *Stahl's sulphureous salt*, having base of fixed vegetable alkali; and so of the rest.

In this Table we have followed Bergman's order of affinity of the sulphuric acid, which is the same in regard to the earths and alkalies; but it is not certain if the order be the same for the metallic oxyds.—A.

SECT. XV.—*Observations upon Sulphurous Acid, and its Combinations.*

The fulphurous acid is formed by the union of oxygen with sulphur, in a lesser degree of oxygenation than the sulphuric acid. It is procurable either by burning sulphur slowly, or by distilling sulphuric acid from silver, antimony, lead, mercury, or charcoal. By these operations a part of the oxygen quits the acid, uniting to these oxydable bases; and the acid passes over in the fulphurous state of oxygenation. This acid, in the common pressure and temperature of the air, can only exist in form of gas. But it appears, from the experiments of Mr Clouet, that, in a very low temperature, it condenses, and becomes fluid. Water absorbs a great deal more of this gas than of carbonic acid gas, but much less than it does of muriatic acid gas.

That the metals cannot be dissolved in acids without being previously oxydated, or by procuring oxygen, for that purpose, from the acids during solution, is a general and well established fact, which I have perhaps repeated too often. Hence, as fulphurous acid is already deprived of great part of the oxygen necessary for forming the sulphuric acid, it is more disposed to recover oxygen, than to furnish it to the greatest part of the metals; and, for this reason, it can-

not dissolve them, unless previously oxydated by other means. From the same principle it is, that the metallic oxyds dissolve without effervescence, and with great facility, in sulphurous acid. This acid, like the muriatic, has even the property of dissolving metallic oxyds furcharged with oxygen, and which are, consequently, insoluble in sulphuric acid: and in this way true sulphats are formed. Hence we might be led to conclude, that there are no metallic sulphites, were it not that the phenomena which accompany the solution of iron, mercury, and some other metals, convince us, that these metallic substances are susceptible of two degrees of oxydation, during their solution in acids. Therefore the neutral salt, in which the metal is least oxydated, must be named *sulphite*; and that in which it is fully oxydated, must be called *sulphat*. It is yet unknown whether this distinction is applicable to any of the metallic sulphats, except those of iron or mercury.

TABLE of the Combinations of the Phosphorous and Phosphoric Acids, with the Salifiable Bases in the Order of Affinity.

<i>Names of the Bases.</i>	<i>Names of the Neutral Salts formed by Phosphorous Acid.      Phosphoric Acid.</i>	
Lime	Phosphites of † lime	Phosphats of † lime.
Strontites	strontites	strontites.
Barytes	barytes	barytes.
Magnesia	magnesia	magnesia.
Potash	potash	potash.
Soda	soda	soda.
Ammoniac	ammoniac	ammoniac.
Argill	argill	argill.
Oxyds of *		
zinc	zinc	zinc.
iron	iron	iron
manganese	manganese	manganese.
cobalt	cobalt	cobalt.
nickel	nickel	nickel
lead	lead	lead.
tin	tin	tin.
copper	copper	copper.
bismuth	bismuth	bismuth.
antimony	antimony	antimony.
arsenic	arsenic	arsenic.
mercury	mercury	mercury.
silver	silver	silver.
gold	gold	gold.
platina	platina	platina.

\* The existence of metallic phosphites supposes that metals are susceptible of solution in phosphoric acid at different degrees of oxygenation, which is not yet ascertained.—A.

† All the phosphites were unknown till lately; and consequently have not hitherto received names.—A.

‡ The greater part of the phosphats were only discovered of late; and have not yet been named.—A.

SECT. XVI.—*Observations upon Phosphorous and Phosphoric Acids, and their Combinations.*

Under the article Phosphorus, Part II. Sect. IX. we have already given a history of the discovery of that singular substance, with some observations upon the mode of its existence in vegetable and animal bodies. The best method of obtaining this acid in a state of purity is by burning well purified phosphorus under bell-glasses, moistened on the inside with distilled water. During combustion it absorbs twice and a half its weight of oxygen ; so that 100 parts of phosphoric acid is composed of  $28\frac{1}{2}$  parts of phosphorus united to  $71\frac{1}{2}$  parts of oxygen. This acid may be obtained concrete, in form of white flakes, which greedily attract the moisture of the air, by burning phosphorus in a dry glass over mercury.

To obtain phosphorous acid, which is phosphorus less oxygenated than in the state of phosphoric acid, the phosphorus must be burnt by a very slow spontaneous combustion over a glass funnel leading into a crystal phial. After a few days, the phosphorus is found oxygenated, and the phosphorous acid, in proportion as it forms, attracts moisture from the air, and drops into the phial. The phosphorous acid is readily changed into phosphoric acid by exposure for a long time

to the free air. It absorbs oxygen from the air, and becomes fully oxygenated.

As phosphorus has a sufficient affinity for oxygen to attract it from the nitric and oxygenated muriatic acids, we may form phosphoric acid, by means of these acids, in a very simple and cheap manner. Fill a tubulated receiver, half full of concentrated nitric acid, and heat it gently: then throw in small pieces of phosphorus through the tube. These are dissolved with effervescence; and red fumes of nitrous gas fly off. Add phosphorus so long as it will dissolve: and then increase the fire under the retort, to drive off the last particles of nitric acid: phosphoric acid, partly fluid and partly concrete, remains in the retort.



TABLE of the Combinations of Carbonic Acid, with the Salifiable Bases, in the Order of Affinity.

Names of the Bases.		Resulting Neutral Salts.	
		New Nomenclature.	Old Nomenclature.
Barytes	Carbonats of* barytes	{	Aërated or Effervescent heavy earth.
Lime	lime		Chalk, Calcareous spar, Aërated calcareous earth.
Strontites	strontites	{	Unknown.
Potash	potash		Effervescing or Aërated fixed vegetable alkali. Mephitic of potash.
Soda	soda	{	Aërated or Effervescing fixed mineral alkali, Mephitic soda.
Magnesia	magnesia		Aërated, effervescing, mild, or mephitic magnesia.
Ammoniac	ammoniac	{	Aërated, effervescing, mild or mephitic, volatile alkali.
Argill	argill		Aërated or effervescing argillaceous earth, or earth of alum.
Oxyds of zinc	zinc	{	Zinc spar, Mephitic or aërated zinc.
iron	iron		Sparry iron-ore, Mephitic or aërated iron.
manganese	manganese	{	Aërated manganese.
cobalt	cobalt		Aërated cobalt.
nickel	nickel	{	Aërated nickel.
lead	lead		Sparry lead-ore, or Aërated lead.
tin	tin	{	Aërated tin.
copper	copper		Aërated copper.
bismuth	bismuth	{	Aërated bismuth.
antimony	antimony		Aërated antimony.
arsenic	arsenic	{	Aërated arsenic.
mercury	mercury		Aërated mercury.
silver	silver	{	Aërated silver.
gold	gold		Aërated gold.
platina	platina	{	Aërated platina.

\* As these salts have only been understood of late, they have not properly speaking, any old names. Mr Morveau, in the first Volume of the Encyclopedia, calls them *Mephites*; Mr Bergman gives them the name of *aërated*; and Mr de Fourcroy, who calls the carbonic acid *chalky acid*, gives them the name of *chalks*—A.

SECT. XVII.—*Observations upon Carbonic Acid, and its Combinations.*

Of all the known acids, the carbonic is the most abundant in nature. It exists ready formed in chalk, marble, and all the calcareous stones, in which it is neutralized by a particular earth, called *lime*. To disengage it from this combination, nothing more is requisite, than to add some sulphuric acid, or any other which has a stronger affinity for lime. A brisk effervescence ensues, which is produced by the disengaged carbonic acid assuming the state of gas, immediately upon being set free. This gas, incapable of being condensed into the solid or liquid form by any degree of cold or of pressure hitherto known, unites to about its own bulk of water, and thereby forms a very weak acid liquor. It may likewise be obtained in great abundance from saccharine matters in fermentation: but is then contaminated by a small portion of alcohol, which it holds in solution.

As carbon is the radical of this acid, we may form it artificially, by burning charcoal in oxygen gas, or by combining charcoal and metallic oxyds in proper proportions. The oxygen of the oxyd combines with the carbon, forming carbonic acid gas: and the metal being left free, recovers its metallic or reguline form.

We are indebted for our first knowledge of this acid to Dr Black, before whose time its property of remaining always in the state of gas had made it elude the researches of chemistry.

It would be a most valuable discovery to society, if we could decompose this gas by any cheap process; as by that means we might obtain, for economical purposes, the immense store of charcoal contained in calcareous earths, marbles, limestones, &c. This cannot be effected by single affinity; because, to decompose the carbonic acid, it requires a substance as combustible as charcoal itself; so that we should only make an exchange of one combustible body for another not more valuable. But it may possibly be accomplished\* by double affinity; since this process is so readily performed by Nature, during vegetation, from the most common materials.

\* Mr Smithson Tennant has given, in the Phil. Transf. for 1791, Art. XI. some experiments on the decomposition of carbonic acid. Some powdered marble, slightly calcined, and some phosphorus, being introduced into a glass tube, coated with a lute of sand and clay, are kept in a red heat for some minutes, and suffered to cool. On breaking the tube, a black powder is found, which consists of charcoal and phosphat of lime. In the laboratory of Dr Black, the decomposition has been produced, *via humida*. Some solution of sulphuret of potash which had stood for several days in an open matrafs, exposed to the air of the room, which had been breathed by several hundred students, was found to have deposited charcoal on the sides of the vessel.—T.

TABLE of the Combinations of Muriatic Acid with  
the Salifiable Bases, in the Order of affinity.

Names of the Bases.		Resulting Neutral Salts.	
	New Nomenclature.	Old Nomenclature.	
Barytes	Muriat of barytes	{ Sea-salt having base of heavy earth.	
Potash	potash	{ Febrifuge salt of Sylvius, Muriated vegetable fixed alkali.	
Soda	soda	{ Sea salt.	
Strontites	strontites	{ Unknown.	
Lime	lime	{ Muriated lime.	
		{ Oil of lime.	
Magnesia	magnesia	{ Marine Epsom salt.	
Ammoniac	ammoniac	{ Muriated magnesia.	
		{ Sal ammoniac.	
Argill	argill	{ Muriated alum, Sea-salt with base of earth of alum.	
Oxyd of zinc	zinc	{ Sea-salt of zinc, or Muriatic zinc.	
iron	iron	{ Salt of iron, or Martial sea-salt.	
manganese	manganese	{ Sea-salt of manganese.	
cobalt	cobalt	{ Sea-salt of cobalt.	
nickel	nickel	{ Sea-salt of nickel.	
lead	lead	{ Horny lead, or Plumbum corneum.	
tin	{ fmoaking, of tin solid, of tin	{ Smoaking liquor of Libavius.	
		{ Butter of tin.	
Copper	copper	{ Sea-salt of copper.	
bismuth	bismuth	{ Sea-salt of bismuth.	
antimony	antimony	{ Sea-salt of antimony.	
arsenic	arsenic	{ Sea-salt of arsenic.	
mercury	{ sweet, of mercury corrosive, of mercury	{ Sweet sublimate of mercury, Calomel, Aquila alba.	
		{ Corrosive sublimate of mercury.	
silver	silver	{ Horny silver, Argentum corneum, Luna cornea.	
gold	gold	{ Sea salt of gold.	
platina	platina	{ Sea-salt of Platina.	

TABLE of the Combinations of Oxygenated Muria-  
tic Acid with the Salifiable Bases, in the Order of  
Affinity.

*Names of the Bases.*                      *Names of the Neutral Salts by  
the New Nomenclature.*

Oxygenated muriat of

Barytes	Barytes.
Potash	potash.
Soda	soda.
Lime	lime.
Magnesia	magnesia.
Argill	argill.
Oxyd of	
zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
tin	tin.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic
mercury	mercury.
silver	silver.
gold	gold.
platina	platina.

This order of salts, entirely unknown to the older chemists, was discovered in 1786 by Mr Berthollet.—A.

SECT. XVIII.—*Observations upon Muriatic and Oxygenated Muriatic Acids, and their Combinations.*

Muriatic acid is very abundant in the mineral kingdom, naturally combined with different salifiable bases, especially with soda, lime, and magnesia. In sea-water, and the water of several lakes, it is combined with these three bases; and in mines of rock-salt it is chiefly united to soda. This acid does not appear to have been hitherto decomposed in any chemical experiment\*; so that we have no idea whatever of the nature of its radical; and only conclude, from analogy with the other acids, that it contains oxygen as its acidifying principle. Mr Berthollet suspects the radical to be of a metallic nature. But, as Nature appears to form this acid daily in inhabited places, by combining miasmata with aeriform fluids, this must necessarily suppose a metallic gas to exist in the atmosphere, which is certainly not impossible, but cannot be admitted without proof.

\* This subject has been already mentioned in some former notes, where the late discovery of this base is said to have been made by Dr Girtanner.—T.



The muriatic acid has only a moderate adherence to the falifiable bafes, and can readily be driven from its combination with thefe by fulphuric acid. Other acids, as the nitric, for instance, may answer the fame purpose. But nitric acid being volatile, would mix, during diftillation, with the muriatic. About one part of fulphuric acid is fufficient to decompose two parts of decrepitated fea-falt. This operation is performed in a tubulated retort, having Woulfe's apparatus, Pl. IV. Fig. 1. adapted to it. When all the junctures are properly luted, the fea-falt is put into the retort, through the tube; the fulphuric acid is poured on; and the opening is immediately clofed by its ground cryftal stopper. As the muriatic acid can only fubfift in the gaffeous form, in the ordinary temperature, we cannot condense it, without the prefence of water. Hence the ufe of the water with which the bottles in Woulfe's apparatus are half filled. The muriatic acid gas, driven off from the fea-falt in the retort, combines with the water; and forms what the old chemifts called *fmoaking fpirit of falt*, or *Glauber's fpirit of fea-falt*, which we now name *muriatic acid*.

The acid obtained by the above procefs is ftill capable of combining with a farther quantity of oxygen, by being diftilled from the oxyds of manganese, lead, or mercury: and the resulting

acid, which we name *oxygenated muriatic acid*, can only, like the former, exist in the gaseous form; and is absorbed, but in a much smaller quantity, by water. When the impregnation of water with this gas is pushed beyond a certain point, the superabundant acid precipitates to the bottom of the vessels, in a concrete form. Mr Berthollet has shown, that this acid is capable of combining with a great number of the salifiable bases. The neutral salts which result from this union are susceptible of deflagrating with charcoal, and with many of the metallic substances. But these deflagrations are very violent and dangerous, owing to the great quantity of caloric which the oxygen carries along with it into the composition of oxygenated muriatic acid\*.

\* It has been formerly mentioned, that *Murioxie acid* would be a more convenient term for this acid, than oxygenated muriatic, the one adopted in the new nomenclature by the French chemists. In this case, the combinations would be named *Murioxats* of barytes, &c.; instead of the much longer, and not more evident, terms of oxygenated muriats.—T.

TABLE of the Combinations of Nitro-muriatic Acid with the Salifiable Bases, in the Order of Affinity, so far as is known.

*Names of the Bases.*

*Names of the Neutral Salts.*

Argill	Nitro-muriat of argill.
Ammoniac	ammoniac.
Oxyd of	
antimony	antimony.
silver	silver.
arsenic	arsenic.
Barytes	barytes
Oxyd of	
bismuth	bismuth.
Lime	lime.
Oxyd of	
cobalt	cobalt.
copper	copper.
tin	tin.
iron	iron.
Magnesia	magnesia.
Oxyd of	
manganese	manganese.
mercury	mercury.
molybdena	molybdena.
nickel	nickel.
gold	gold.
platina	platina.
lead	lead.
Potash	potash.
Soda	soda.
Oxyd of	
tungstein	tungstein.
zinc	zinc.

*Note*—Most of these combinations, especially those with the earths and alkalies, have been little examined: and we are yet to learn whether they form a mixed salt, in which the compound radical remains combined, or if the two acids separate, to form two distinct neutral salts.—A.

SECT. XIX.—*Observations upon the Nitro-Muriatic\* Acid, and its combinations.*

The nitro-muriatic acid, formerly called *aqua regia*, is formed by a mixture of nitric and muriatic acids. The radicals of these two acids combine together, and form a compound base, from which an acid is produced, having properties peculiar to itself, and distinct from those of all other acids, especially the power of dissolving gold and platina.

In dissolutions of metals in this acid, as in all other acids, the metals are first oxydated by attracting a part of the oxygen from the compound radical. This occasions a disengagement of a particular species of gas, not hitherto described, which may be called *nitro-muriatic gas*. It has a very disagreeable smell, and is fatal to animal life when respired. It attacks iron, and causes it to rust. It is absorbed in considerable quantity by water, which thereby acquires some slight characters of acidity. I had occasion to make these remarks during a course of experiments

\* Azo-muriatic would perhaps answer better as a term for this compound acid; Azo-muria having been, in a former note, proposed as a more convenient name for the base than the more lengthened expression of Nitro-muriatic radical.—T.

upon platina, in which I dissolved a considerable quantity of that metal in nitro-muriatic acid.

I at first suspected, that, in the mixture of nitric and muriatic acids, the latter attracted a part of the oxygen from the former, and became converted into oxygenated muriatic acid, which gave it the property of dissolving gold. But several facts remain inexplicable upon this supposition. Were it so, we should be able to disengage nitrous gas by heating this acid, which however does not sensibly happen. From these considerations, I am led to adopt the opinion of Mr Berthollet, and to consider nitro-muriatic acid as a single acid, with a compound base or radical.

TABLE of the Combinations of Fluoric Acid, with  
the Salifiable Bases, in the Order of Affinity.

*Names of the Bases*

*Names of the Neutral Salts.*

Lime

Fluat of lime\*.

Barytes

barytes.

Strontites

strontites.

Magnesia

magnesia.

Potash

potash

Soda

soda.

Ammoniac

ammoniac.

Oxyd of

zinc

zinc.

manganese

manganese.

iron

iron.

lead

lead.

tin

tin.

cobalt

cobalt.

copper

copper.

nickel

nickel.

arsenic

arsenic.

bismuth

bismuth.

mercury

mercury.

silver

silver.

gold

gold.

platina

platina.

And, by the dry way,

Argill

Fluat of argill.

*Note.*—These combinations were entirely unknown to the old chemists, and consequently have no names in the old nomenclature.—A.

\* Fluor spar, or Vitreous spar.



SECT. XX.—*Observations upon the Fluoric Acid, and its combinations.*

Fluoric acid exists ready formed by Nature, in the fluoric spars\*, combined with calcareous earth, so as to form an insoluble neutral salt. To obtain it, disengaged from that combination, fluor spar, or fluat of lime, is put into a leaden retort, with a proper quantity of sulphuric acid. A recipient, likewise of lead, half full of water, is adapted, and fire is applied to the retort. The sulphuric acid, from its greater affinity, expels the fluoric acid, which passes over and is absorbed by the water in the receiver. As fluoric acid is naturally in the gaseous form in the ordinary temperature, we can receive it in a pneumato-chemical apparatus over mercury. We are obliged to employ metallic vessels in this process; because fluoric acid dissolves glass and siliceous earth, and even renders these bodies volatile, carrying them over with itself in distillation in the gaseous form.

We are indebted to Mr Margraff for our first acquaintance with this acid; though, as he could

\* The beautiful spars from Derbyshire are of this kind.  
—T.

never procure it free from combination with a considerable quantity of siliceous earth, he was ignorant of its being an acid *fui generis*. The Duke de Liancourt, under the name of Mr Boulanger, has considerably increased our knowledge of its properties, and Mr Scheele seems to have exhausted the subject. The only thing remaining is to endeavour to discover the nature of the fluoric radical, of which we cannot hitherto form any idea; as the acid does not appear to have been decomposed in any experiment. It is only by means of compound affinity that experiments ought to be made with this view, with any probability of success.

TABLE of the Combination of Boracic Acid, with  
the Salifiable Bases, in the Order of Affinity.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime*	Borat of lime.
Barytes	barytes.
Strontites	strontites.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Oxyd of	
zinc	zinc.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
mercury	mercury.
Argill	argill.

*Note*—Most of these combinations were neither known, nor named by the old chemists. The boracic acid was formerly called *sedative salt*, and its compounds *borax*, with base of fixed vegetable alkali, &c.—A.

\* By Dr Hope's experiments, in his paper on strontites, read to the Royal Society of Edinburgh, lime follows barytes; and the superiority between lime and strontites is uncertain.—T.

SECT. XXI.—*Observations upon Boracic Acid, and its Combinations.*

This is a concrete acid, extracted from a salt procured in India, called *borax* or *tincall*. Although borax has been very long employed in the arts, we have as yet very imperfect knowledge of its origin, and of the methods by which it is extracted and purified. There is reason to believe it to be a native salt, found in the earth in certain parts of the east, and in the water of some lakes. The whole trade of borax is in the hands of the Dutch, who have been exclusively possessed of the art of purifying it, till very lately, when Messrs L'Eguillier of Paris have rivalled them in the manufacture. But the process still remains a secret to the world.

By chemical analysis we learn that borax is a neutral salt with excess of base, consisting of soda, partly saturated with a peculiar acid, long called *Homborg's sedative salt*, now *the boracic acid*. This acid is found in an uncombined state in the waters of certain lakes: That of Cherchia in Italy contains  $94\frac{1}{2}$  grains in each pint of water.

To obtain boracic acid, dissolve some borax in boiling water; filtrate the solution; and add

fulphuric acid, or any other having greater affinity to soda than the boracic acid. This latter acid is separated, and is procured in a crystalline form by cooling. This acid was long considered as being formed during the process by which it is obtained; and was consequently supposed to differ according to the nature of the acid employed in separating it from the soda. But it is now universally acknowledged, that it is identically the same acid, in whatever way procured, provided it be properly purified from mixture of other acids, by washing, and by repeated solution and crystallization. It is soluble both in water and alcohol, and has the property of communicating a green colour to the flame of that spirit. This circumstance led to a suspicion of its containing copper, which is not confirmed by any decisive experiment. On the contrary, if it contain any of that metal, it must only be considered as an accidental mixture. It combines with the salifiable bases in the humid way; and though, in this manner, it is incapable of dissolving any of the metals directly, this combination is readily effected by compound affinity.

The Table presents its combinations in the order of affinity in the humid way. But there is a considerable change in the order, when we operate *via sicca*; for, in that case, argill,

though the last in our list, must be placed immediately after soda.

The boracic radical is hitherto unknown, no experiments having as yet been able to decompose the acid. But we conclude, from analogy with the other acids, that oxygen exists in its composition, as the acidifying principle.



TABLE of the Combinations of *Arsenic Acid*,  
with the *Salifiable Bases*, in the Order of *Affinity*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Arseniat of lime.
Barytes	barytes.
Strontites	strontites.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
bismuth	bismuth.
mercury	mercury.
antimony	antimony.
silver	silver.
gold	gold.
platina	platina.
Argill	argill.

*Note.*—This order of salts was entirely unknown to the old chemists. Mr Macquer, in 1746, discovered the combinations of arsenic acid with potash and soda, to which he gave the name of *arsenical neutral salts*.—A.

SECT. XXII.—*Observations upon Arseniac Acid, and its Combinations.*

In the Collections of the Academy for 1746, Mr Macquer shews, that, when a mixture of white oxyd of arsenic and nitre are subjected to the action of a strong fire, a neutral salt is obtained, which he calls *neutral salt of arsenic*. At that time, the cause of this singular phenomenon, in which a metal acts the part of an acid, was quite unknown. But more modern experiments teach, that, during this process, the arsenic becomes oxygenated, by carrying off the oxygen of the nitric acid. It is thus converted into a real acid, and combines with the potash. There are other methods now known for oxygenating arsenic, and obtaining its acid free from combination. The most simple and most effectual of these is as follows: Dissolve white oxyd of arsenic in three parts, by weight, of muriatic acid. To this solution, in a boiling state, add two parts of nitric acid, and evaporate to dryness. In this process, the nitric acid is decomposed; its oxygen unites with the oxyd of arsenic, and converts it into an acid; and the nitrous radical flies off in the state of nitrous gas; while the muriatic acid is converted by the heat into muriatic acid gas, and

may be collected in proper vessels. The arseniac acid is entirely freed from the other acids employed, during the process by heating it in a crucible till it begins to grow red. What remains is pure concrete arseniac acid.

Mr Scheele's process, which was repeated with great success by Mr Morveau, in the laboratory at Dijon, is as follows: Distil muriatic acid from the black oxyd of manganese. This converts it into oxygenated muriatic acid, by carrying off the oxygen from the manganese. Receive this oxygenated acid in a recipient, containing white oxyd of arsenic, covered by a little distilled water. The arsenic decomposes the oxygenated muriatic acid, by carrying off its super-saturation of oxygen, and is converted into arseniac acid, while the oxygenated muriatic acid is brought back to the state of common muriatic acid. The two acids are separated by distillation with a gentle heat increased towards the end of the operation. The muriatic acid passes over, and the arseniac acid remains behind in a white concrete form.

The arseniac acid is considerably less volatile than white oxyd of arsenic. It often contains white oxyd of arsenic in solution, owing to its not being sufficiently oxygenated. This is prevented by continuing to add nitrous acid, as in the former process, till no more nitrous gas is produced. From all these observations I

would give the following definition of arseniac acid. It is a white concrete metallic acid, formed by the combination of arsenic with oxygen; it is fixed in a red heat, is soluble in water, and is capable of combining with many of the salifiable bases.

SECT. XXIII.—*Observations upon Molybdic Acid, and its Combinations with Acidifiable Bases* \*.

Molybdena is a particular metallic body, capable of being oxygenated, so far as to become a true concrete acid†. For this purpose, one part by weight of the ore of molybdena, which is a natural sulphuret of that metal, is put into a retort, with five or six parts of nitric acid, diluted with a quarter of its weight of water, and heat is applied to the retort. The oxygen of the nitric acid acts both upon the molybdena and the sulphur, converting the one into molybdic, and the other into sulphuric acid. Pour on fresh quantities of nitric acid so long as any red fumes

\* I have not added the Table of these combinations, as the order of their affinity is entirely unknown; they are called *molybdats of argill, antimony, potash, &c.*—T.

† This acid was discovered by Mr Scheele, to whom chemistry is indebted for the discovery of several other acids.—A.

of nitrous gas escape. The molybdena is then oxygenated as far as is possible; and is found at the bottom of the retort in a pulverulent form, resembling chalk. It must be washed in warm water, to separate any adhering particles of sulphuric acid; and, as it is hardly soluble, we lose very little of it in this operation. All its combinations with salifiable bases were unknown to the old chemists\*.

\* Messrs Tondi and Ruprecht have lately reduced Molybdena to the reguline state, by a similar process to that formerly described for reducing the metals of Chalk, Magnesia, and Barytes. They describe the metallic button as being convex and compact, and resembling steel in its colour, its fracture is uneven and granulated, and has more metallic lustre internally than on the surface. It is brittle, not hard, and not attractible by the magnet. On the surface of one of the buttons procured in these experiments, some little cavities were observed, in which the metal had crystallized in form of prismatic needles, which were too small to allow of their particular configuration being accurately determined. The specific gravity of this metal, according to the experiments of Mr Haidinger, councillor of the Schemnitz mines, is 6.963, water being taken as 1.000.—T.

TABLE of the Combinations of Tungstic Acid, with  
the Salifiable Bases.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Tungstat of lime.
Barytes	barytes.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of antimony*, &c.	antimony†, &c.

SECT. XXIV.—*Observations upon Tungstic Acid,  
and its Combinations.*

Tungstein is a particular metal, the ore of which has frequently been confounded with that of tin. The specific gravity of this ore is to water as 6 to 1. In its form of crystallization it resembles the garnet, and varies in colour

\* The combinations with metallic oxyds are set down by Mr Lavoisier in alphabetical order, their order of affinity being unknown. I have omitted them as serving no purpose.—T.

† All these salts were unknown to the old chemists.—A.



from a pearl-white to a yellow and reddish. It is found in several parts of Saxony and Bohemia. The mineral called *Wolfram*, which is frequent in the mines of Cornwall, is likewise an ore of this metal. In all these ores, the metal is oxydated: and, in some of them, it appears even to be oxygenated to the state of acid, being combined with lime into a true tungstat of lime.

To obtain the acid free, mix one part of ore of tungstein with four parts of carbonat of potash, and melt the mixture in a crucible. Then powder it, and pour on twelve parts of boiling water; add nitric acid, and the tungstic acid precipitates in a concrete form. Afterwards, to insure the complete oxygenation of the metal, add more nitric acid, and evaporate to dryness, repeating this operation so long as red fumes of nitrous gas are produced. To procure tungstic acid perfectly pure, the fusion of the ore with carbonat of potash must be made in a crucible of platina; otherwise the earth of the common crucibles will mix with the products, and adulterate the acid.

TABLE of the Combinations of Tartarous Acid, with  
the Salifiable Bases, in the Order of Affinity.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Tartarite of lime.
Barytes	barytes.
Strontites	strontites.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of	
zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
tin	tin.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic.
silver	silver.
mercury	mercury.
gold	gold.
platina	platina.

SECT. XXV.—*Observations upon Tartarous Acid, and its Combinations.*

Tartar, or the concretion which fixes to the inside of vessels in which the fermentation of wine is completed, is a well known salt, composed of a peculiar acid, united, in considerable excess, to potash. Mr Scheele first pointed out the method of obtaining this acid pure. Having observed, that it has a greater affinity to lime than to potash, he directs us to proceed in the following manner. Dissolve purified tartar in boiling water, and add a sufficient quantity of lime, till the acid be completely saturated. The tartarite of lime, which is thus formed, being almost insoluble in cold water, falls to the bottom, and is separated from the solution of potash by decantation. . It is afterwards washed in cold water, and dried. Then some sulphuric acid, diluted with eight or nine parts of water, is poured on. Digest for twelve hours in a gentle heat, frequently stirring the mixture, and the sulphuric acid combines with the lime, leaving the tartarous acid free. A small quantity of gas, not hitherto examined, is disengaged during this process. At the end of twelve hours, having decanted off the clear liquor, wash the sulphat of lime in cold water, which add to the decanted liquor; then evaporate the whole; and

the tartarous acid is obtained in a concrete form. Two pounds of purified tartar, by means of from eight to ten ounces of sulphuric acid, yield about eleven ounces of tartarous acid.

As the combustible radical exists in excess, or as the acid from tartar is not fully saturated with oxygen, we call it *tartarous acid*; and the neutral salts, formed by its combinations with salifiable bases, are named *tartarites*. The base of the tartarous acid is a carbon-hydrous or hydro-carbonous radical, less oxygenated than in the oxalic acid; and it would appear, from the experiments of Mr Hassenfratz, that azot enters into the composition of the tartarous radical, even in considerable quantity. By oxygenating tartarous acid still farther, it is convertible into oxalic, malic, and acetic acids. But it is probable the proportions of hydrogen and carbon in the radical, are changed, during these conversions; and that the difference between these acids does not alone consist in the different degrees of oxygenation.

The tartarous acid is susceptible of two degrees of saturation in its combinations with the fixed alkalies. By one of these a salt is formed with excess of acid, improperly called *cream of tartar*, which, in our new nomenclature, is named *acidulous tartarite of potash*. By a second or reciprocal degree of saturation, a perfectly neutral salt is formed, formerly called *vegetable*

*salt*, which we name *tartarite of potash*. With soda this acid forms tartarite of soda, formerly called *sal de Seignette*, or *sal polychrest of Rochelle*\*.

SECT. XXVI.—*Observations upon Malic Acid, and its Combinations with the Salifiable Bases*†.

The malic acid exists ready formed in the four juice of ripe and unripe apples, and many other fruits, and is obtained as follows: Saturate the juice of apples with potash or soda, and add a proper proportion of acetite of lead dissolved in water; a double decomposition takes place, the malic acid combines with the oxyd of lead, and precipitates, being almost insoluble; and the acetite of potash or soda remains in the liquor. The malat of lead being separated by decantation, is washed with cold water, and some diluted sulphuric acid is added; this unites with the lead into an insoluble sulphat, and the malic acid remains free in the liquor.

\* This account of the composition of Rochelle salt is not quite accurate. It is a triple salt, consisting of tartarous acid, saturated by soda and potash; and is formed by completely neutralizing acidulous tartarite of potash, by the addition of a sufficient quantity of soda.—T.

† I have omitted the Table, as the order of affinity is unknown, and is given by Mr Lavoisier only in alphabetical order. All the combinations of malic acid with salifiable bases, which are named *malats*, were unknown to the old chemists.—T.

This acid, which is found mixed with citric and tartarous acid, in a great number of fruits, is a kind of medium between the oxalic and acetic acids, being more oxygenated than the former, and less so than the latter. From this circumstance, Mr Hermbstadt calls it *imperfect vinegar*; but it differs likewise from acetic acid, by having rather more carbon, and less hydrogen, in the composition of its radical.

When an acid much diluted has been used in the foregoing process, the liquor contains oxalic as well as malic acid, and probably a little tartarous. These are separated by mixing lime-water with the acids, oxalat, tartarite, and malat of lime are produced. The two former, being insoluble, are precipitated, and the malat of lime remains dissolved; from this the pure malic acid is separated by the acetite of lead, and afterwards by sulphuric acid, as directed above.



TABLE of the Combinations of Citric Acid, with the Salifiable Bases, in the Order of Affinity\*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Barytes	Citrat of barytes.
Lime	lime.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
cobalt	cobalt.
copper	copper.
arsenic	arsenic
mercury	mercury.
antimony	antimony.
silver	silver.
gold	gold.
platina	platina.
Argill	argill.

\* These combinations were unknown to the old chemists. The order of affinity of the salifiable bases with this acid was determined by Mr Bergman, and by Mr de Breney of the Dijon Academy.—A.

SECT. XXVII.—*Observations upon Citric Acid, and its Combinations.*

The citric acid is procured by expression from lemons, and is found in the juices of many other fruits, mixed with malic acid. To obtain it pure and concentrated, it is first allowed to depurate from the mucous part of the fruit, by long rest in a cool cellar, and is afterwards concentrated by exposing it to the temperature of from  $21^{\circ}$  to  $23^{\circ}$  of Fahrenheit. The water is thereby frozen, and the acid remains liquid, reduced to about an eighth part of its original bulk. A lower degree of cold would occasion the acid to be engaged among the ice, and render it difficultly separable. This process was pointed out by Mr Georgius.

It is more easily obtained by saturating the lemon-juice with lime, so as to form a citrat of lime, which is insoluble in water. Wash this salt, and pour on a proper quantity of sulphuric acid. This forms a sulphat of lime, which precipitates and leaves the citric acid free in the liquor.

TABLE of the Combinations of Pyro-lignous Acid with the Salifiable Bases, in the Order of Affinity\*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Pyro-lignite of lime.
Barytes	barytes.
Potash	potash.
Soda	soda.
Magnesia	magnesia.
Ammoniac	ammoniac.
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
arsenic	arsenic.
bismuth	bismuth.
mercury	mercury.
antimony	antimony.
silver	silver.
gold	gold.
platina	platina.
Argill	argill.

\* The above affinities were determined by Messrs de Morveau and Eloi Bourcier de Clervaux. These combinations were entirely unknown till lately.—A.

SECT. XXVIII.—*Observations upon the Pyro-lignous Acid, and its Combinations.*

The old chemists observed, that most of the woods, especially the more heavy and compact ones, give out a particular acid spirit, by distillation in a naked fire. But, before Mr Goetling, who gives an account of his experiments upon this subject in Crell's Chemical Journal for 1779, no one had ever made any inquiry into its nature and properties. This acid appears to be the same, whatever be the wood it is procured from. When first distilled, it is of a brown colour, and considerably impregnated with carbon and oil. It is purified from these by a second distillation. The pyro-lignous radical is chiefly composed of hydrogen and carbon.

SECT. XXIX.—*Observations upon Pyro-tartarous Acid, and its Combinations with the Salifiable Bases\*.*

The name of *Pyro-tartarous Acid* is given to a diluted empyreumatic acid, obtained from puri-

\* The order of affinity of the salifiable bases with this acid, is hitherto unknown. Mr Lavoisier, from its similarity

fied acidulous tartarite of potash, by distillation in a naked fire. To obtain it, let a retort be half-filled with powdered tartar; adapt a tubulated recipient, having a bent tube communicating with a bell-glass in a pneumat-chemical apparatus. By gradually raising the fire under the retort, we obtain the pyro-tartarous acid mixed with oil, which is separated by means of a funnel. A vast quantity of carbonic acid gas is disengaged during the distillation. The acid obtained by the above process, is much contaminated with oil, which ought to be separated from it. Some authors advise to do this by a second distillation; but the Dijon academicians inform us, that this is attended with great danger, from explosions which take place during the process.

to pyro-lignous acid, supposes the order to be the same in both; but, as this is not ascertained by experiment, the table is omitted. All those combinations, called *Pyro-tartarites*, were unknown till lately.—T.

TABLE of the Combinations of Pyro-mucous Acid, with the Salifiable Bases, in the Order of Affinity\*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Potash	Pyro-mucite of potash.
Soda	soda.
Barytes	barytes
Lime	lime.
Magnesia	magnesia.
Ammoniac	ammoniac.
Argill	argill
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
arsenic	arsenic.
bismuth	bismuth.
antimony	antimony.

\* All these combinations were unknown to the old chemists.—A.



SEC. XXX.—*Observations upon Pyro-mucous Acid, and its Combinations.*

This acid is obtained by distillation in a naked fire from sugar, and all the saccharine bodies; and, as these substances swell greatly in the fire, it is necessary to leave seven-eighths of the retort empty. It is of a yellow colour, verging to red, and leaves a mark upon the skin, which will not remove but along with the epidermis. It may be procured less coloured, by means of a second distillation; and is concentrated by freezing, as is directed for the citric acid. It is chiefly composed of water and oil, slightly oxygenated; and is convertible into oxalic and malic acids, by farther oxygenation with the nitric acid.

It has been pretended, that a large quantity of gas is disengaged during the distillation of this acid, which is not the case, if it be conducted slowly, by means of moderate heat.

TABLE of the Combinations of the Oxalic Acid, with  
the Salifiable Bases, in the Order of Affinity\*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Oxalat of lime.
Barytes	barytes.
Strontites	strontites.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of	
zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic
mercury	mercury.
silver	silver.
gold	gold.
platina	platina.

\* All unknown to the old chemists.—A.

SECT. XXXI.—*Observations upon Oxalic Acid, and its Combinations.*

The oxalic acid is mostly prepared in Switzerland and Germany from the expressed juice of sorrel, from which it crystallizes by being left long at rest. In this state it is partly saturated with potash, forming a true acidulous oxalat of potash, or salt with excess of acid. To obtain it pure, it must be formed artificially by oxygenating sugar, which seems to be the true oxalic radical. Upon one part of sugar, pour six or eight parts of nitric acid, and apply a gentle heat, a considerable effervescence takes place, and a great quantity of nitrous gas is disengaged. The nitric acid is decomposed, and its oxygen unites to the sugar. By allowing the liquor to stand at rest, crystals of pure oxalic acid are formed, which must be dried upon blotting paper, to separate any remaining portions of nitric acid; and, to ensure the purity of the acid, dissolve the crystals in distilled water, and crystallize them afresh.

From the liquor remaining after the first crystallization of the oxalic acid, we may obtain malic acid by refrigeration. This acid is more oxygenated than the oxalic; and by a further

oxygenation, the fugar is convertible into acetous acid, or vinegar.

The oxalic acid, combined with a small quantity of soda or potash, has the property, like the tartarous acid, of entering into a number of combinations without suffering decomposition. These combinations form triple salts, or neutral salts with double bases, which ought to have proper names. The salt of sorrel, which is potash having oxalic acid combined in excess, is named acidulous oxalat of potash, in our new nomenclature.

The acid procured from sorrel has been known to chemists for more than a century, being mentioned by Mr Ducloux in the Memoirs of the Academy for 1688 ; and was pretty accurately described by Boerhaave. But Mr Scheele first shewed that it contained potash, and demonstrated its identity with the acid formed by the oxygenation of fugar.

SECT. XXXII.—*Observations upon Acetous Acid, and its Combinations.*

This acid is composed of carbon and hydrogen united together, and brought to the state of an acid by the addition of oxygen. It is consequently formed of the same elements with the tartarous, oxalic, citric, and malic acids, and

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*TABLE of the Combinations of Acetous Acid with the Salifiable Bases in the Order of Affinity.*

<i>Bases.</i>	<i>Neutral Salts.</i>	<i>Names of the resulting Neutral Salts, according to the Old Nomenclature.</i>
Barytes - -	Acetite of barytes -	Unknown to the old chemists. Discovered by Mr de Morveau, who calls it <i>barotic acide</i> .
Potash - -	_____ potash -	Secret terra foliata tartari, of Muller. Arcanum tartari, of Basil Valentin and Paracelsus.
Soda - -	_____ foda -	Purgative magistery of tartar, of Schroöder. Essential salt of wine of Zwelfer. Regenerated tartar, of Tachenius. Diuretic salt, of Sylvius and Wilson.
Lime - -	_____ lime -	Foliated earth with base of mineral alkali. Mineral or crystallisable foliated earth. Mineral acetous salt.
Magnesia -	_____ magnesia	Salt of chalk, coral, or crabs eyes; mentioned by Hartman.
Ammoniac -	_____ ammoniac	First mentioned by Mr Wenzel.
Oxyd of zinc -	_____ zinc -	Spiritus Mindereri. Ammoniacal acetous salt.
_____ manganese	_____ manganese	Known to Glauber, Schwedemberg, Respour, Pott, de Laffone, and Wenzel, but not named.
_____ iron -	_____ iron -	Unknown to the old chemists.
_____ lead -	_____ lead -	Martial vinegar. Described by Monnet, Wenzel, and the Duke d'Ayen
_____ tin - -	_____ tin - -	Sugar, vinegar, and salt, of lead or of Saturn.
_____ cobalt -	_____ cobalt -	Known to Lemery, Margraff, Monnet, Wessendorff, and Wenzel, but not named.
_____ copper -	_____ copper -	Sympathetic ink of Mr Cadet.
_____ nickel -	_____ nickel -	Verdigris, crystals of verditer, verditer, distilled Verdigris, crystals of Venus or of copper.
_____ arsenic -	_____ arsenic -	Unknown to the old chemists.
_____ bismuth	_____ bismuth	Arsenico-acetous fuming liquor, or liquid phosphorus of Mr Cadet.
_____ mercury	_____ mercury	Sugar of bismuth of Mr Geoffroi. Known to Gellert, Pott, Wessendorff, Bergman, and de Morveau.
_____ antimony	_____ antimony	Mercurial foliated earth, Keyser's famous antivenerial remedy. Mentioned by Gebaver in 1748; known to Helot, Margraff, Baumé, Bergman, and de Morveau.
_____ silver -	_____ silver -	Unknown.
_____ gold -	_____ gold -	Described by Margraff, Monnet, and Wenzel; unknown to the old chemists.
_____ platina -	_____ platina -	Little known, mentioned by Scheroöder and Juncker.
Argill - - -	_____ argill -	Unknown.
		According to Mr Wenzel, vinegar dissolves only a small proportion of argill.

others : but the elements exist in different proportions in each of these ; and it would appear that the acetous acid is in a higher state of oxygenation than these other acids. I have some reason to believe that the acetous radical contains a small portion of azot ; and, as this element is not contained in the radicals of any vegetable acid, except the tartarous, this circumstance is one of the causes of difference. The acetous acid, or vinegar, is produced by exposing wine to a gentle heat, with the addition of some ferment. This is usually the ley, or mother, which has separated from other vinegar during fermentation, or some similar matter. The spirituous part of the wine, which consists of carbon and hydrogen, is oxygenated, and converted into vinegar. This operation can only take place with free access of air, and is always attended by a diminution of the air employed, in consequence of the absorption of oxygen ; wherefore it ought always to be carried on in vessels only half filled with the vinous liquor submitted to the acetous fermentation.

The acid formed during this process, is very volatile. It is mixed with a large proportion of water, and with many foreign substances : and to obtain it pure, it must be distilled, in stone or glass vessels, by a gentle fire. The acid which passes over in distillation, is somewhat changed by the process ; and is not exactly of the same



nature with what remains in the alembic, but seems less oxygenated. This circumstance has not been formerly observed by chemists.

Distillation is not sufficient for depriving this acid of all its unnecessary water; and, for this purpose, the best way is by exposing it to a degree of cold, of from  $19^{\circ}$  to  $23^{\circ}$  of Fahrenheit. By this means the aqueous part becomes frozen, and leaves the acid in a liquid state, and considerably concentrated. In the usual temperature of the air, this acid can only exist in the gaseous form, and can only be retained by combination with a large proportion of water. There are other chemical processes for obtaining the acetous acid, which consist in oxygenating the tartarous, oxalic, or malic acids, by means of nitric acid. But there is reason to believe the proportions of the elements of the radical are changed during this process. Mr. Hassenfratz is at present engaged in repeating the experiments by which these conversions are said to be produced.

The combinations of acetous acid with the various salifiable bases are very readily formed. But most of the resulting neutral salts are not crystallizable; whereas those produced by the tartarous and oxalic acids are, in general, hardly soluble. Tartarite and oxalat of lime are not soluble in any sensible degree. The malats are a medium between the oxalats and acetites,

with respect to solubility, and the malic acid is in the middle degree of saturation between the oxalic and acetous acids. With this, as with all the acids, the metals require to be oxydated previous to solution.

The older chemists knew hardly any of the salts formed by the combinations of acetous acid with the salifiable bases, except the acetites of potash, soda, ammoniac, copper, and lead. Mr Cadet discovered the acetite of arsenic\*. Mr Wenzel, and the Dijon academicians, Mr de Laffone and Mr Proust, made us acquainted with the properties of the other acetites. From the property which acetite of potash possesses, of giving out ammoniac in distillation, there is some reason to suppose, that besides carbon and hydrogen, the acetous radical contains a small proportion of azot; though it is not impossible but the above production of ammoniac may be occasioned by the decomposition of the potash.

\* Savans Etrangers, Vol. III.

*TABLE of the Combinations of Acetic Acid, with  
the Salifiable Bases, in the Order of Affinity.*

<i>Bases.</i>	<i>Neutral Salts.</i>
Barytes	Acetat of barytes.
Potash	potash.
Soda	soda.
Lime	lime.
Magnesia	magnesia.
Ammoniac	ammoniac.
Oxyd of zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
arsenic	arsenic.
bismuth	bismuth.
mercury	mercury.
antimony	antimony.
silver	silver.
gold	gold.
platina	platina.
Argill	argill.

*Note.*—All these salts were unknown to the older chemists : And even those, who are most versant in modern discoveries, are yet at a loss whether the greater part of the salts produced by the oxygenated acetic radical belong properly to the class of acetites, or to that of acetats.—A.

SECT. XXXIII.—*Observations upon Acetic Acid, and its Combinations.*

We have given to radical vinegar the name of acetic acid, from supposing that it consists of the same radical with that of the acetous acid, but more highly saturated with oxygen. According to this idea, acetic acid is the highest degree of oxygenation of which the hydro-carbonous radical is susceptible ; but, although this circumstance be extremely probable, it requires to be confirmed by farther and more decisive experiments, before it be adopted as an absolute chemical truth. We procure this acid as follows : Upon three parts acetite of potash or of copper, pour one part of concentrated sulphuric acid, and, by distillation, a very highly concentrated vinegar is obtained, which we call acetic acid, formerly named radical vinegar. It is not hitherto rigorously proved, that this acid is more highly oxygenated than the acetous acid, nor that the difference between them may not consist in a different proportion between the elements of the radical or base.

TABLE of the combinations of Succinic Acid with the Salifiable Bases, in the Order of Affinity.

<i>Bases.</i>	<i>Neutral Salts.</i>
Barytes	Succinat of barytes.
Lime	lime.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Magnesia	magnesia.
Argill	argill.
Oxyd of zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
tin	tin.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic.
mercury	mercury.
silver	silver.
gold	gold.
platina	platina.

*Note.*—All the succinats were unknown to the older chemists.  
—A.

SECT. XXXIV.—*Observations upon Succinic Acid, and its Combinations.*

The succinic acid is drawn from amber by sublimation in a gentle heat ; and rises, in a concrete form, into the neck of the subliming vessel. The operation must not be pushed too far, or by too strong a fire, otherwise the oil of the amber rises with the acid. The salt is dried upon blotting paper, and purified by repeated solution and crystallization.

The acid is soluble in twenty-four times its weight of cold water, and in a much smaller quantity of hot water. It possesses the qualities of an acid in a very small degree, and only affects the blue vegetable colours very slightly. The affinities of this acid, with the salifiable bases, are taken from Mr de Morveau, who is the first chemist that has endeavoured to ascertain them.



SECT. XXXV.—*Observations upon Benzoic Acid, and its Combinations with Salifiable Bases*\*.

This acid was known to the ancient chemists under the name of the Flowers of Benjamin, or of Benzoin, and was procured by sublimation, from the gum or resin called Benzoin. The means of procuring it, *via humida*, was discovered by Mr Geoffroy, and perfected by Mr Scheele. Upon benzoin, reduced to powder, pour strong lime-water, having rather an excess of lime. Keep the mixture continually stirring; and, after half an hour's digestion, pour off the liquor, and use fresh portions of lime-water in the same manner, so long as there is any appearance of neutralization. Join all the decanted liquors, and evaporate as far as possible, without occasioning crystallization; and, when the liquor is cold, drop in muriatic acid, till no more precipitate is formed. By the former part of the process a benzoat of lime is formed; and, by the latter, the muriatic acid combines with the lime, forming muriat of lime, which remains

\* These combinations are called Benzoats of Lime, Potash, Zinc, &c; but, as the order of affinity is unknown, the alphabetical table is omitted, as unnecessary.—T.

dissolved, while the benzoic acid, being insoluble, precipitates in a concrete form.

SECT. XXXVI. — *Observations upon Camphoric Acid, and its Combinations with Salifiable Bases\**.

Camphor is a concrete essential oil, obtained, by sublimation, from a species of laurus which grows in China and Japan. By distilling nitric acid eight times from camphor, Mr Kosegarten converted it into an acid, analogous to the oxalic. But, as it differs from that acid in some circumstances, we have thought necessary to give it a particular name, till its nature be more completely ascertained by farther experiment.

As camphor is a carbonohydrous or hydrocarbonous radical, it is easily conceived, that, by oxygenation, it should form oxalic, malic, and several other vegetable acids. This conjecture is rendered not improbable by the experiments of Mr Kosegarten; and the principal phenomena exhibited in the combinations of camphoric acid with the salifiable bases, being

\* These combinations, which were all unknown to the old chemists, are called Camphorats. The table is omitted, as being only in alphabetical order.—T.

very similar to those of the oxalic and malic acids, lead me to believe, that it consists of a mixture of these two acids.

SECT. XXXVII.—*Observations upon Gallic Acid, and its Combinations with Salifiable Bases* \*.

The Gallic acid, formerly called the Principle of Astringency, is obtained from gall-nuts, either by infusion or decoction with water, or by distillation with a very gentle heat. This acid has only been attended to within these few years. The committee of the Dijon Academy have followed it through all its combinations, and give the best account of it hitherto produced. Its acid properties are very weak. It reddens the tincture of turnsol; decomposes sulphurets; and unites to all the metals, when they have been previously dissolved in some other acid. Iron, by this combination, is precipitated of a very deep blue or violet colour. The radical of this acid, if it deserve the name of one, is hitherto entirely unknown: it is contained in

\* These combinations, which are called Gallats, were all unknown to the older chemists; and the order of their affinity is not hitherto established.—A.

oak, willow, marsh iris, the strawberry, nymphaea, Peruvian bark, the flowers and bark of pomegranate and in many other woods and barks.

SECT. XXXVIII.—*Observations upon Lactic Acid, and its Combinations with Salifiable Bases* \*.

The only accurate knowledge we have of this acid is from the works of Mr Scheele. It is contained in whey, united to a small quantity of earth, and is obtained as follows: Reduce whey to one eighth part of its bulk by evaporation, and filtrate, to separate all its cheesy matter. Then add as much lime as is necessary to combine with the acid. The lime is afterwards disengaged by the addition of oxalic acid, which combines with it into an insoluble neutral salt. When the oxalat of lime has been separated by decantation, evaporate the remaining liquor to the consistence of honey. The lactic acid is dissolved by alkohol, which does not unite with the sugar of milk and other foreign matters. These are separated by filtration from the alkohol

\* These combinations are called Lactats. They were all unknown to the older chemists; and their affinities have not yet been ascertained.—A.

and acid : and the alkohol being evaporated or distilled off, leaves the lactic acid behind.

This acid unites with all the salifiable bases, forming salts which do not crystallize ; and it seems considerably to resemble the acetic acid.

*TABLE of the Combinations of Saccho-lactic Acid  
with the Salifiable Bases, in the Order of  
Affinity.*

<i>Bases.</i>	<i>Neutral Salts.</i>
Lime	Saccholat of lime.
Barytes	barytes.
Magnesia	magnesia.
Potash	potash.
Soda	soda.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
arsenic	arsenic.
bismuth	bismuth.
mercury	mercury.
antimony	antimony.
silver	silver.

*Note.*—All these were unknown to the older chemists.—A.



SECT. XXXIX.—*Observations upon Saccho-lactic Acid, and its Combinations.*

A species of sugar may be extracted, by evaporation, from whey. This substance has long been known in pharmacy, and has a considerable resemblance to that procured from the sugar-cane. This saccharine matter, like ordinary sugar, may be oxygenated by means of nitric acid. For this purpose, several portions of nitric acid are distilled from it. The remaining liquid is evaporated, and set to crystallize, by which means crystals of oxalic acid are procured. At the same time a very fine white powder precipitates, which is the saccho-lactic acid discovered by Scheele. It is susceptible of combining with all the alkalies, with the earths, and even with the metals. Its action upon the latter is hitherto but little known, except that, with them, it forms difficultly soluble salts. The order of affinity in the table is taken from Bergman.

TABLE of the Combinations of Formic Acid with  
the Salifiable Bases, in the Order of Affinity.

<i>Bases.</i>	<i>Neutral Salts.</i>
Barytes	Formiat of barytes.
Potash	potash.
Soda	soda.
Lime	lime.
Magnesia	magnesia.
Ammoniac	ammoniac.
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
bismuth	bismuth.
silver	silver.
Argill	argill.

Y y

*Note.*—All unknown to the older chemists.—A.

SECT. XL.—*Observations upon Formic Acid, and its Combinations.*

This acid was first obtained, by distillation from ants, in the last century, by Samuel Fisher. The subject was treated of by Margraff, in 1749, and by Messrs Ardvisson and Ochrn of Leipsic, in 1777. The formic acid is extracted from a large species of red ants, *formica rufa*, Lin. which form large ant hills in woody places. It is procured, either by distilling the ants with a gentle heat in a glass retort or an alembic; or, after having washed the ants in cold water, and dried them upon a cloth, by pouring on boiling water, which dissolves the acid; or the acid may be procured by gentle expression from the insects, in which case it is stronger than in any of the former ways. To obtain it pure, we must rectify, by means of distillation, which separates it from the uncombined oily and charry matter; and it may be concentrated by freezing, in the manner recommended for treating the acetous acid.

SECT. XLI.—*Observations upon Bombic Acid, and its Combinations with Acidifiable Bases* \*.

The juices of the silk-worm seem to assume an acid quality when that insect changes from the larva to the chrysalis state. At the moment of its escape from the latter to the butterfly form, it emits a reddish liquor, which reddens blue paper, and which was first attentively observed by Mr Chauffier of the Dijon Academy. He obtained the acid by infusing silk-worm chrysalids in alcohol, which dissolves their acid without being charged with any of the gummy parts of the insect; and, by evaporating the alcohol, the acid remains tolerably pure. The properties and affinities of this acid are not hitherto ascertained with any precision: and we have reason to believe, that analogous acids may be procured from other insects. The radical of this acid is probably, like that of the other acids from the animal kingdom, composed of carbon, hydrogen, and azot, with the addition, perhaps, of phosphorus.

\* These combinations, named Bombats, were unknown to the old chemists; and the affinities of the salifiable bases with the bombic acid are hitherto undetermined.—A.

*TABLE of the Combinations of the Sebacic Acid,  
with the Salifiable Bases, in the Order of  
Affinity.*

<i>Bases.</i>	<i>Neutral Salts.</i>
Barytes	Sebat of barytes.
Potash	potash.
Soda	soda.
Lime	lime.
Magnesia	magnesia.
Ammoniac	ammoniac.
Argill	argill.
Oxyd of	
zinc	zinc.
manganese	manganese.
iron	iron.
lead	lead.
tin	tin.
cobalt	cobalt.
copper	copper.
nickel	nickel.
arsenic	arsenic.
bismuth	bismuth.
mercury	mercury.
antimony	antimony.
silver	silver.

*Note.*—All these were unknown to the old chemists.—A.

SECT. XLII.—*Observations upon Sebacic Acid,  
and its Combinations.*

To obtain the sebacic acid, let some suet be melted in a skillet over the fire, with some quick-lime in fine powder, and constantly stirred, raising the fire towards the end of the operation, and taking care to avoid the vapours, which are very offensive. By this process the sebacic acid unites with the lime into a sebat of lime, which is difficultly soluble in water. It is, however, separated from the fatty matters with which it is mixed by solution in a large quantity of boiling water. From this the neutral salt is separated by evaporation; and, to render it pure, is calcined, re-dissolved, and again crystallized. After this we pour on a proper quantity of sulphuric acid, and the sebacic acid passes over by distillation.



SECT. XLIII.—*Observations upon the Lithic Acid, and its Combinations with the Salifiable Bases* \*.

From the later experiments of Bergman and Scheele, the urinary calculus appears to be a species of salt with an earthy basis. It is flighty acidulous, and requires a large quantity of water for solution, three grains being scarcely soluble in a thousand parts of boiling water; and the greater part again crystallizes when cold. To this concrete acid, which Mr De Morveau calls the Lithiasic, we give the name of Lithic Acid, the nature and properties of which are hitherto very little known. There is some appearance that it is an acidulous neutral salt, or acid combined in excess with a salifiable base; and I have reason to believe, that it really is an acidulous phosphat of lime; if so, it must be excluded from the class of peculiar acids.

\* All the combinations of this acid, should it finally turn out to be one, were unknown to the older chemists; and its affinities with the salifiable bases have not been hitherto determined.—A.

TABLE of the Combinations of the Prussic Acid, with the Salifiable Bases, in the order of Affinity\*.

<i>Bases.</i>	<i>Neutral Salts.</i>
Potash	Prussiat of potash.
Soda	soda.
Ammoniac	ammoniac.
Lime	lime.
Barytes	barytes.
Magnesia	magnesia.
Oxyd of zinc	zinc.
iron	iron.
manganese	manganese.
cobalt	cobalt.
nickel	nickel.
lead	lead.
tin	tin.
copper	copper.
bismuth	bismuth.
antimony	antimony.
arsenic	arsenic.
silver	silver.
mercury	mercury.
gold	gold.
platina	platina.

\* All these were unknown to former chemists.—A.

SECT. XLIV.—*Observations upon the Prussic Acid, and its Combinations.*

As the experiments which have been made hitherto upon this acid seem still to leave a considerable degree of uncertainty with regard to its nature, I shall not enlarge upon its properties, and the means of procuring it pure and disengaged from combination. It combines with iron to which it communicates a blue colour; and is equally susceptible of entering into combination with most of the other metals, which are precipitated from it by the alkalies, ammoniac, and lime, in consequence of greater affinity. The Prussic radical, from the experiments of Scheele, and especially from those of Mr Berthollet, seems composed of carbon and azot; hence it is an acid with a double base. The phosphorus, which has been found combined with it, appears, from the experiments of Mr Hassenfratz, to be only accidental.

Although this acid combines with alkalies, earths, and metals, in the same way with other acids, it possesses only some of the properties we have been in use to attribute to acids: and it may consequently be improperly ranked here in the class of acids. But, as I have already observed, it is difficult to form a decided opinion

upon the nature of this substance, until the subject has been farther elucidated by a greater number of experiments.

SECT. XLV.—*Recapitulation of the foregoing Observations on the Acids, and their Combinations* \*.

It was thought, that it might be conducive to the convenience and information of the reader, to subjoin the two following tables. The first, which is only a recapitulation of what is contained in the foregoing sections, gives a general view of the order of the affinities of the salifiable bases with the several acids, so far as is hitherto known. Such acids as have a similar order of affinity with these bases, are placed together, at the head of the same column; and those of which the order of affinity, between them and the bases, have not been hitherto ascertained, are omitted.

The second table contains a specimen of a general view of the new chemical nomenclature, as applied to the neutral salts, both in Latin

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\* The whole of this section was added to the second edition by the Translator.

and English. The first column contains the names of the several acids; the second is a list of the Latin terms for the neutral salts which these produce by union with the salifiable bases, as proposed in the new French chemical nomenclature; the third is a systematic translation of these terms into English, on exactly analagous principles; the fourth contains another system of Latin nomenclature, founded on that of the French chemists, but following rather the plan of Bergman, as already noticed in some notes; the fifth and last column is an analagous English translation of these terms.

In the former of these tables, the nomenclature recommended by Dr Black, as already mentioned in some former notes, is adopted for the alkaline and earthy salifiable bases. In the latter, the nomenclature used by the French chemists for these substances, is retained in the second and third sections; but the proposed alteration is introduced in the fourth and fifth, together with a similar alteration, likewise formerly mentioned in some notes, for giving names to the metallic oxyds, to distinguish these from the reguline or perfectly simple state, analagous to alkalies. To translate this last idea of nomenclature into English, required such a violent change, that the usual names of the metals in English are retained; that, however,

can induce no ambiguity, and it must be generally understood, that no metal can enter into combination with an acid, unless it be previously oxydated.



TABLE OF THE ACIDS IN THE ORDER OF AFFINITY.

I.	II.	III.	IV.
Nitrous, Nitric, Sulphurous, Sulphuric, Mu- riatic, and Se- bacic Acid.	Acetous, Ace- tic, and For- mic Acids.	Boracic Acid.	Nitro-muriatic Acid.
Baryta. Lixa. Trona. Calca. Magnesia. Ammonia. Arga. Oxyds of Zinc. Iron. Manganese. Cobalt. Nickel. Lead. Tin. Copper. Bismuth. Antimony. Arsenic. Mercury. Silver. Gold. Platina.	Baryta. Lixa. Trona. Calca. Magnesia. Ammonia. Oxyds of Zinc. Manganese. Iron. Lead. Tin. Cobalt. Copper. Nickel. Arsenic. Bismuth. Mercury. Antimony. Silver. Gold. Platina. Arga.	Calca. Baryta. Magnesia. Lixa. Trena. Ammonia. Oxyds of Zinc. Iron. Lead. Tin. Cobalt. Copper. Nickel. Mercury. Arga.	Arga. Ammonia. Oxyds of Antimony. Silver. Arsenic. Baryta. Oxyd of Bismuth. Calca. Oxyds of Cobalt. Copper. Tin. Iron. Magnesia. Oxyds of Manganese. Mercury. Molybdena. Nickel. Gold. Platina. Lead. Lixa. Trona. Oxyds of Tungstein. Zinc.

V.	VI.	VII.
Phosphorous, Phosphoric, Tungstic, Tartarous, Oxalic and Saccho-lactic Acids.	Carbonic Acid.	Murioxie Acid.
Calca. Baryta. Magnesia. Lixa. Trona. Ammonia. Arga. Oxyds as in Col. I.	Baryta. Calca. Lixa. Trona. Magnesia. Ammonia. Arga. Oxyds as in Col. I.	Baryta. Lixa. Trona. Calca. Magnesia. Arga. Oxyds as in Col. I.
VIII.	IX.	X.
Fluoric and Arseniac Acids.	Citric Acid.	Pyro-lignous Acid.
Calca. Baryta. Magnesia. Lixa. Trona. Ammonia. Oxyds as in Col. II. Arga.	Baryta. Calca. Magnesia. Lixa. Trona. Ammonia. Oxyds as in Col. II. omitting Tin, Nickel, and Bismuth. Arga.	Calca. Baryta. Lixa. Trona. Magnesia. Ammonia. Oxyds as in Col. II. Arga.
XI.	XII.	XIII.
Pyro-mucous Acid	Succinic Acid.	Prussic Acid.
Lixa. Trona. Baryta. Calca. Magnesia. Ammonia. Arga. Oxyds as in Col. II omitting silver, Gold and Platina.	Baryta. Calca. Lixa. Trona. Ammonia. Magnesia. Arga. Oxyds as in Col. I.	Lixa. Trona. Ammonia. Calca. Baryta. Magnesia. Oxyds as in Col. I. placing Silver before Mercury.

TABLE OF THE NOMENCLATURE

Acids.	Lavoisier.	
	Latin.	English.
Sulphurous.	Sulphis potassæ	Sulphite of potash
	—fodæ	—of soda
	—ammoniæ	—of ammoniac
Sulphuric.	Sulphas calcis	Sulphat of lime
	—magnesiæ	—of magnesia
	—barytæ	—of barytes
	—argillæ	—of argill
Phosphorous.	Phosphis potassæ	Phosphite of Potash
Phosphoric.	Phosphas fodæ	Phosphat of soda
Nitrous.	Nitris ammoniæ	Nitrite of ammoniac
Nitric.	Nitras argenti	Nitrat of silver
Oxygenated Nitric.	—auri oxygenata	Oxygenated nitrat of gold
Muriatic.	Murias mercurii	Muriat of mercury
Oxygenated Muriatic.	—potassæ oxygenata	Oxygenated muriat of potash
Boracic.	Boras fodæ	Borat of soda
Acetous.	Acetis ammoniæ	Acetite of ammoniac
Acetic, &c.	Acetas cupri, &c.	Acetat of copper, &c.

## OF THE NEUTRAL SALTS.

Proposed Alteration.	
Latin.	English.
Lixa fulphurosa	Sulphurous lixa
Trona fulphurosa	—— trona
Ammona fulphurosa	—— ammona
Calca fulphurica	Sulphuric calca
Magnesia fulphurica	—— magnesia
Baryta fulphurica	—— baryta
Arga fulphurica	—— arga
Lixa phosphorosa	Phosphorous lixa
Trona phosphorica	Phosphoric trona
Ammona nitrosa	Nitrous ammona
Argenta nitrica	Nitric silver
Aura nitroxica	Nitroxie gold
Mercuria muriatica	Muriatic Mercury
Lixa murioxica	Murioxie lixa
Trona boracica	Boracic trona
Ammona acetosa	Acetous ammona
Cupra acetica, &c.	Acetic copper, &c.



## PART III.

*Description of the Instruments and  
Operations of Chemistry.*

## INTRODUCTION.

**I**N the two former parts of this work, I designedly avoided being particular in describing the manual operations of chemistry; because I had found, from experience, that, in a work appropriated to reasoning, minute descriptions of processes and of plates interrupt the chain of ideas, and render the necessary attention both difficult and tedious to the reader. On the other hand, if I had confined myself to the summary descriptions hitherto given, beginners could have only acquired very vague conceptions of practical chemistry from my work; and must have wanted both confidence and interest in operations which they could neither repeat nor



thoroughly comprehend. This want could not have been supplied from books; for, besides that there are not any which describe the modern instruments and experiments sufficiently at large, any work that could have been consulted, would have presented these things under a very different order of arrangement, and in a different chemical language; which must greatly tend to injure the main object of my performance.

Influenced by these motives, I determined to reserve, for a third part of my work, a summary description of all the instruments and manipulations relative to elementary chemistry. I consider it as better placed at the end than at the beginning of the book; because, otherwise, I must have been obliged to suppose the reader conversant with circumstances, which a beginner cannot know, and to become acquainted with which he must have previously read the elementary part. The whole of this third part may, therefore, be considered as resembling the explanations of plates, which are usually placed at the end of academic memoirs, that they may not interrupt the connection of the text, by lengthened description.

Though I have taken great pains to render this part clear and methodical, and have not omitted any essential instrument or apparatus,

I am far from pretending by it to set aside the necessity of attendance upon lectures and laboratories, for such as wish to acquire accurate knowledge of the science of chemistry. These should familiarise themselves to the employment of apparatus, and to the performance of experiments by actual experience. *Nil est in intellectu quod non prius fuerit in sensu*, the motto which the celebrated Rouelle caused to be painted in large characters on a conspicuous part of his laboratory, is an important truth never to be lost sight of either by teachers or students of chemistry.

Chemical operations may be naturally divided into several classes, according to the purposes they are intended for performing. Some may be considered as purely mechanical, such as the determination of the weight and bulk of bodies, trituration, levigation, searching or sifting, washing, filtration, &c. Others may be considered as real chemical operations; because they are performed by means of chemical powers and agents; such as solution, fusion, &c. Some of these are intended for separating the elements of bodies from each other; some for reuniting these elements together; and some, as combustion, produce both these effects during the same process.

Without rigorously endeavouring to follow the above method, I mean to give a detail of

the chemical operations in such order of arrangement as seems best calculated for conveying instruction. I shall be more particular in describing the apparatus connected with modern chemistry; because these are hitherto little known by men, who have devoted much of their time to chemistry, and even by many professors of the science.

CHAP.

## C H A P. I.

*Of the Instruments necessary for determining the Absolute and Specific Gravities of Solid and Liquid Bodies.*

THE best method hitherto known for determining the quantities of substances submitted to chemical experiment, or resulting from them, is by means of accurately constructed beams and scales, with properly regulated weights; which well-known operation is called *weighing*. The denomination and quantity of the weight used as an unit or standard for this purpose, are extremely arbitrary; and vary, not only in different kingdoms, but even in different provinces of the same kingdom, and in different cities of the same province. This variation is of infinite consequence to be well understood in commerce and in the arts; but, in chemistry, it is of no moment what particular denomination of weight be employed, provided the results of experiments be expressed in convenient fractions of the same denomination. For this purpose, until all the weights used in society be reduced to the same standard, it will be sufficient for che-

mists in different parts, to use the common pound of their own country, as the unit or standard, and to express all its fractional parts in decimals, instead of the arbitrary divisions now in use. By this method the chemists of all countries will be thoroughly understood by each other; as, although the absolute weights of the ingredients and products cannot be known, they will readily, and without calculation, be able to determine the relative proportions of these to each other with the utmost accuracy; so that in this way we shall be possessed of an universal language for this part of chemistry.

With this view I have long projected to have the pound divided into decimal fractions; and I have of late succeeded, through the assistance of Mr. Fourche, balance-maker at Paris, who has executed it for me with great accuracy and judgment. I recommend to all who carry on experiments to procure similar divisions of the pound, which they will find both easy and simple in its application, with a very small knowledge of decimal fractions\*.

\* Mr. Lavoisier gives, in this part of his work, very accurate directions for reducing the common subdivisions of the French pound into decimal fractions, and *vice versa*, by means of tables, subjoined to this 3d part. As these instructions, and the table, would be useless to the British chemist, from the difference between the subdivisions of the

As the usefulness and accuracy of chemistry depend entirely upon the determination of the weights of the ingredients and products, both before and after experiments, too much precision cannot be employed in this part of the subject; and, for this purpose, we must be provided with good instruments. As we are often obliged, in chemical processes, to ascertain, within a grain or less, the tare or weight of large and heavy instruments, we must have beams made with peculiar nicety by accurate workmen; and these must always be kept apart from the laboratory, in some place where the vapours of acids, or other corrosive liquors, cannot have access; otherwise the steel will rust, and the accuracy of the balance be destroyed. I have three sets, of different sizes, made by Mr. Fontin with the utmost nicety; and, excepting those made by Mr. Ramsden of London, I do not think any can compare with them for precision and sensibility. The largest of these is about three feet long in the beam for large weights, up to fifteen or twenty pounds. The second, for weights of eighteen or twenty ounces, is exact

French and Troy pounds, I have omitted them; but have subjoined, in the appendix, accurate rules for converting the one denomination into the other, together with tables for reducing the various divisions of our Troy pound into decimals, and for converting these decimals into the ordinary divisions.—T.



to a tenth part of a grain; and the smallest, calculated only for weighing about one dram, is sensibly affected by the five hundredth part of a grain.

Besides these nicer balances, which are only used for experiments of research, we must have others of less value, for the ordinary purposes of the laboratory. A large iron balance, capable of weighing forty or fifty pounds, within half a dram; one of a middle size, which may ascertain eight or ten pounds, within ten or twelve grains; and a small one, by which about a pound may be determined within one grain.

We must likewise be provided with weights divided into their several fractions, both vulgar and decimal, with the utmost nicety, and verified by means of repeated and accurate trials in the nicest scales: and it requires some experience, and to be accurately acquainted with the different weights, to be able to use them properly. The best way of precisely ascertaining the weight of any particular substance, is to weigh it twice, once with the decimal divisions of the pound, and another time with the common subdivisions or vulgar fractions; and, by comparing these, we attain the utmost accuracy.

By the specific gravity of any substance is understood the quotient of its absolute weight divided by its magnitude, or, what is the same, the weight of a determinate bulk of any body.

The weight of a determinate magnitude of water has been generally assumed as unity for this purpose; and we express the specific gravity of gold, sulphuric acid, &c. by saying, that gold is nineteen times; and sulphuric acid twice the weight of water; and so of other bodies.

It is the more convenient to assume water as unity in specific gravities, that those substances whose specific gravity we wish to determine, are most commonly weighed in water for that purpose. Thus, if we wish to determine the specific gravity of gold flattened under the hammer, and supposing the piece of gold to weigh  $48989\frac{1}{2}$  *grs.* in the air\*, it is suspended by means of a fine metallic wire under the scale of a hydrostatic balance, so as to be entirely immersed in water, and again weighed. The piece of gold in Mr. Briffon's experiment, lost by this means 253 *grs.*; and, as it is evident that the weight lost by a body weighed in water is precisely equal to the weight of the water displaced, or to that of an equal volume of water, we may conclude, that, in equal magnitudes, gold weighs  $4898\frac{1}{2}$  *grs.* and water 253 *grs.* which, reduced to unity, gives 1.0000 as the specific gravity of water, and 19.3617 for that of gold. We may operate in the same manner with all solid substances. We have, however,

\* Vide Mr. Briffon's Essay upon Specific Gravity, p. 5.  
—A. B b b

rarely any occasion, in chemistry, to determine the specific gravity of solid bodies, unless when operating upon alloys or metallic glasses; but we have very frequent necessity to ascertain that of fluids, as it is often the only means of judging of their purity or degree of concentration.

This object may be very fully accomplished, with the hydrostatic balance, by weighing a solid body, such, for example, as a little ball of rock crystal, suspended by a very fine gold wire, first in the air, and afterwards in the fluid whose specific gravity we wish to discover. The weight lost by the crystal, when weighed in the liquor, is equal to that of an equal bulk of the liquid. By repeating this operation successively in water and different fluids, we can very readily ascertain, by a simple and easy calculation, the relative specific gravities of these fluids, either with respect to each other or to water. This method is not, however, sufficiently exact, or, at least, is rather troublesome, from its extreme delicacy, when used for liquids differing but little in specific gravity from water; such, for instance, as mineral waters, or any other water containing very small portions of salt in solution.

In some operations of this nature, which have not hitherto been made public, I employed an instrument of great sensibility for this pur-

pose with great advantage. It consists of a hollow cylinder, *A b c f*, Pl. vii. fig. 6. of brass, or rather of silver, loaded at its bottom, *b c f*, with tin, as represented swimming in a jug of water, *l m n o*. To the upper part of the cylinder is attached a stalk of silver wire, not more than three-fourths of a line in diameter, surmounted by a little cup *d*, intended for containing weights; upon the stalk a mark is made at *g*, the use of which we shall presently explain. This cylinder may be made of any size; but, to be accurate, ought at least to displace four pounds of water. The weight of tin with which this instrument is loaded, ought to be such as will make it remain almost in equilibrium in distilled water; and should not require more than half a dram, or a dram at most, to make it sink to *g*.

We must first determine, with great precision, the exact weight of the instrument, and the number of additional grains requisite for making it sink, in distilled water of a determinate temperature, to the mark. We then perform the same experiment upon all the fluids of which we wish to ascertain the specific gravities; and by means of calculation, reduce the observed differences to a common standard of cubic feet, pints, or pounds, or of decimal fractions, comparing them with water. This me-

thod, joined to experiments with certain reagents\*, is one of the best for determining the quality of waters, and is even capable of pointing out differences which escape the most accurate chemical analysis. I shall, at some future period, give an account of a very extensive set of experiments which I have made upon this subject.

These metallic hydrometers are only to be used for determining the specific gravities of such waters as contain only neutral salts or alkaline substances; and they may be constructed with different degrees of ballast for alcohol and other spiritous liquors. When the specific gravities of acid liquors are to be ascertained, we must use a glass hydrometer, as represented Pl. vii. fig. 14†. This consists of a hollow cylinder of glass, *a b c f*, hermetically sealed at its lower end, and drawn out at the upper extremity, into a capillary tube *a*, ending in the little cup or basin *d*. This instrument is ballasted with more or less mercury, at the bottom of the cylinder, introduced through the tube, in pro-

\* For the use of these reagents see Bergman's excellent treatise upon the analysis of mineral waters, in his Chemical and Physical Essays.—T.

† Some years ago, that is, before 1787, I have seen similar glass hydrometers, made for Dr. Black by P. Knie, a very ingenious artist of this city.—T.



portion to the weight of the liquor intended to be examined. We may introduce a small graduated slip of paper into the tube *a d*; and, though these degrees do not exactly correspond to the fractions of grains in the different liquors, they may be rendered very useful in calculation.

What is said in this chapter may suffice, without farther enlargement, for indicating the means of ascertaining the absolute and specific gravities of solids and fluids, as the necessary instruments are generally known, and may easily be procured. But, as the instruments I have used for measuring the gasses are not any where described, I shall give a more detailed account of these in the following chapter.

## CHAP.



## C H A P II.

*Of Gazometry, or the Measurement of the Weight  
and Volume of Aëriform Substances.*

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## S E C T. I.

*Description of the Pneumato-chemical Apparatus.*

THE French chemists have of late applied the name of *pneumato-chemical apparatus* to the very simple and ingenious contrivance, invented by Dr. Priestly, which is now indispensibly necessary to every laboratory. This consists of a wooden trough, of larger or smaller dimensions, as is thought convenient, lined with plate-lead or tinned copper, as represented in perspective, Pl. V.—In Fig. 1. the same trough or cistern is supposed to have two of its sides cut away, to shew its interior construction more distinctly. In this apparatus, we distinguish between the shelf ABCD Fig. 1. and 2. and the bottom or body of the cistern FGHI Fig. 2.

The jars or bell-glasses are filled with water in this deep part, and, being turned with their mouths downwards, are afterwards set upon the shelf ABCD, as shewn Plate X. Fig. 1. F.—The upper parts of the sides of the cistern, above the level of the shelf, are called the *rim* or *borders*.

The cistern ought to be filled with water, so as to stand at least an inch and a half deep over the shelf; and it should be of such dimensions as to admit of at least one foot of water in every direction in the well, or cistern. The size above described is sufficient for ordinary occasions; but it is often convenient, and even necessary, to have more room. I would therefore advise such as intend to employ themselves usefully in chemical experiments, to have this apparatus made of considerable magnitude, where their place of operating will allow. The well of my principal cistern holds four cubical feet of water, and its shelf has a surface of fourteen square feet: yet, in spite of this size, which I at first thought immoderate, I am often straitened for room.

In laboratories, where a considerable number of experiments are performed, it is necessary to have several lesser cisterns, besides the large one which may be called the *general magazine*; and even some portable ones, which may be moved when necessary, near a furnace, or wherever they may be wanted. There are likewise some

operations which dirty the water of the apparatus, and therefore require to be carried on in cisterns by themselves.

It were doubtless considerably cheaper to use cisterns of wood, simply dove-tailed, or iron-bound tubs, instead of being lined with lead or copper; and in my first experiments I used them made in that way; but I soon discovered their inconvenience. If the water be not always kept at the same level, such of the dovetails as are left dry, shrink, and, when more water is added, it escapes through the joints, and runs out.

We employ crystal jars or bell glasses, Pl. V. Fig. 9. A. for containing the gasses in this apparatus. And, for transporting these, when full of gas, from one cistern to another, or for keeping them in reserve, when the cistern is too full, we make use of a flat dish BC, surrounded by a standing up rim or border, with two handles DE for carrying it by.

After several trials of different materials, I have found marble the best substance for constructing the mercurial pneumato-chemical apparatus; as it is perfectly impenetrable by mercury, and is not liable, like wood, to separate at the junctures, or to allow the mercury to escape through chinks; neither does it run the risk of breaking, like glass, stone-ware, or porcelain. Take a block of marble BCDE, Plate V. Fig. 3.

and 4. about two feet long, 15 or 18 inches broad, and ten inches thick, and cause it to be hollowed out, as at *m n*, Fig. 5. about four inches deep, as a reservoir for the mercury; and, to be able more conveniently to fill the jars, cut the gutter *T V*, Fig. 3. 4. and 5. at least four inches deeper; and as this trench may sometimes prove troublesome, it is made capable of being covered at pleasure by thin boards, which slip into the grooves *x y*, Fig. 5. I have two marble cisterns upon this construction, of different sizes, by which I can always employ one of them as a reservoir of mercury, which it preserves with more safety than any other vessel, being neither subject to overturn, nor to any other accident. We operate with mercury in this apparatus exactly as with water in the one before described; but the bell-glasses must be of smaller diameters, and much stronger; or we may use glass tubes, having their mouths widened, as in Fig. 7.; these are called *eudiometers*, by the glass-men who sell them. One of the bell-glasses is represented Fig. 5. *A*. standing in its place; and what is called a jar is engraved at Fig. 6.

The mercurial pneumato-chemical apparatus is necessary in all experiments wherein the disengaged gasses are capable of being absorbed by water; as is frequently the case, especially in all combinations, excepting those of metals, in fermentation, &c.

## S E C T. II.

*Of the Gazometer.*

I give the name of *gazometer* to an instrument which I invented, and caused to be constructed, for the purpose of a kind of bellows, which might furnish an uniform and continued stream of oxygen gas in experiments of fusion. Mr Meusnier and I have since made very considerable corrections and additions, having converted it into what may be called an *universal instrument*, without which it is hardly possible to perform most of the very exact experiments. The name we have given the instrument indicates its intention for measuring the volume or quantity of gas submitted to it for examination.

It consists of a strong iron beam, DE, Pl. VIII. Fig. 1, three feet long, having at each end, D, and E, a segment of a circle, likewise strongly constructed of iron, and very firmly joined. Instead of being poised as in ordinary balances, this beam rests, by means of a cylindrical axis of polished steel, F, Fig. 9. upon two large moveable brass friction-wheels, by which the resistance to its motion from friction is considerably diminished, being converted into friction of the second order. As an additional precau-



tion, the parts of these wheels which support the axis of the beam are covered with plates of polished rock-cryſtal. The whole of this machinery is fixed to the top of the ſolid column of wood BC, Fig. 1. To one extremity D of the beam, a ſcale P, for holding weights, is ſuſpended by a flat chain, which applies to the curvature of the arc *nDo*, in a groove made for the purpoſe. To the other extremity E of the beam is applied another flat chain, *i k m*, ſo conſtructed, as to be incapable of lengthening or ſhortening, by being leſs or more charged with weight. To this chain, an iron trivet, with three branches, *ai*, *ci*, and *bi*, is ſtrongly fixed at *i*; and theſe branches ſupport a large inverted jar A, of hammered copper, about 18 inches diameter, and 20 inches deep. The whole of this machine is repreſented in perſpective, Pl. VIII. Fig. 1: and Pl. IX. Fig. 2. and 4. give perpendicular ſections, which ſhew its interior ſtructure.

Round the bottom of the jar, on its outſide, is fixed, Pl. IX. Fig. 2. a border divided into compartments 1, 2, 3, 4, &c. intended to receive leaden weights ſeparately repreſented 1, 2, 3, Fig. 3. Theſe are intended for increaſing the weight of the jar, when a conſiderable preſſure is requiſite, as will be afterwards explained, though ſuch neceſſity ſeldom occurs. The cylindrical jar A is entirely open below, *de*, Pl. IX. Fig. 4.; but is cloſed above, with a copper



lid  $abc$ , open at  $bf$ , and capable of being shut by the cock  $g$ . This lid, as may be seen by inspecting the figures, is placed a few inches within the top of the jar, to prevent the jar from being ever entirely immersed in the water, and covered over. Were I to have this instrument made over again, I should cause the lid to be considerably more flattened, so as to be almost level. This jar or reservoir of air is contained in the cylindrical copper vessel LMNO, Pl. VIII. Fig. 1. filled with water.

In the middle of the cylindrical vessel LMNO, Pl. IX. Fig. 4. are placed two tubes  $st$ ,  $xy$ , which are made to approach each other at their upper extremities  $ty$ . These are made of such a length as to rise a little above the upper edge LM of the vessel LMNO: and when the jar  $abcde$  touches the bottom NO, their upper ends enter about half an inch into the conical hollow  $b$ , leading to the stop-cock  $g$ .

The bottom of the vessel LMNO is represented Pl. IX. Fig. 3. in the middle of which a small hollow hemispherical cap is soldered, which may be considered as the broad end of a funnel reversed; the two tubes  $st$ ,  $xy$ , Fig. 4. are adapted to this cap at  $s$  and  $x$ , and by this means communicate with the tubes  $mm$ ,  $nn$ ,  $oo$ ,  $pp$ , Fig. 3. which are fixed horizontally upon the bottom of the vessel, and all of which terminate in, and are united by, the spherical cap  $sx$ . Three of

these tubes are continued out of the vessel, as in Pl. VIII. Fig. 1. The first marked in that figure 1, 2, 3, is inserted at its extremity 3, by means of an intermediate stop-cock 4, to the jar V. which stands upon the shelf of a small pneumato-chemical apparatus GHIK, the inside of which is shewn Pl. IX. Fig. 1. The second tube is applied against the outside of the vessel LMNO from 6 to 7; is continued at 8, 9, 10; and at 11 is engaged below the jar V. The former of these tubes is intended for conveying gas into the machine, and the latter for conducting small quantities for trials under jars. The gas is made either to flow into or out of the machine, according to the degree of pressure it receives; and this pressure is varied at pleasure, by loading the scale P less or more, by means of weights. When gas is to be introduced into the machine, the pressure is taken off, or even rendered negative; but when gas is to be expelled, a pressure is made with such degree of force as is found necessary.

The third tube 12, 13, 14, 15, is intended for conveying air or gas to any necessary place or apparatus for combustions, combinations, or any other experiment in which it may be required.

To explain the use of the fourth tube, I must enter into some discussions. Suppose the vessel LMNO, Pl. VIII. Fig. 1. full of water, and the jar A partly filled with gas, and partly with water; it is evident that the weights in the ba-

son P may be so adjusted, as to occasion an exact equilibrium between the weight of the basin and of the jar, so that the external air shall not tend to enter into the jar, nor the gas to escape from it: and in this case, the water will stand exactly at the same level, both within and without the jar. On the contrary, if the weight in the basin P be diminished, the jar will then press downwards from its own gravity, and the water will stand lower within the jar than it does without: in this case, the included air or gas will suffer a degree of compression above that experienced by the external air, exactly proportioned to the weight of a column of water, equal to the difference of the external and internal surfaces of the water.

From these reflections, Mr Meusnier contrived a method of determining the exact degree of pressure to which the gas contained in the jar is at any time exposed. For this purpose, he employs a double glass syphon, 19, 20, 21, 22, 23, firmly cemented at 19 and 23. The extremity 19 of this syphon communicates freely with the water in the external vessel of the machine: and the extremity 23 communicates with the fourth tube, at the bottom of the cylindrical vessel; and consequently by means of the perpendicular tube *st*, Pl. IX. Fig. 4. with the air contained in the jar. He likewise cements, at 16, Pl. VIII. Fig. 1. another glass tube, 16, 17, 18, which

communicates at 16 with the water in the exterior vessel LMNO; and, at its upper end 18, is open to the external air.

By these several contrivances, it is evident, that the water must stand in the tube 16, 17, 18, at the same level with that in the cistern LMNO; and, on the contrary, that, in the branch 19, 20, 21, it must stand higher or lower according as the air in the jar is subjected to a greater or lesser pressure than the external air. To ascertain these differences, a brass scale, divided into inches and lines, is fixed between these two tubes. It is readily conceived, that, as air, and all other elastic fluids, must increase in weight by compression, it is necessary to know their degree of condensation, to be enabled to calculate their quantities, and to convert the measure of their volumes into correspondent weights: and this object is intended to be fulfilled by the contrivance now described.

But, to determine the specific gravity of air, or of gasses, and to ascertain their weight in a known volume, it is necessary to know their temperature, as well as the degree of pressure under which they subsist: and this is accomplished by means of a small thermometer, strongly cemented into a brass collet, which screws into the lid of the jar A. This thermometer is represented separately, Pl. VIII. Fig. 10. and in its place 24, 25, Fig. 1. and Pl. IX. Fig. 4. The bulb is

in the inside of the jar A, and its graduated stalk rises on the outside of the lid.

The practice of gazometry would still have laboured under great difficulties, without farther precautions than those above described. When the jar A sinks in the water of the cistern LMNO, it must lose a weight equal to that of the water which it displaces; and consequently the compression which it makes upon the contained air or gas must be proportionally diminished. Hence the gas furnished, during experiments, from the machine, will not have the same density towards the end, which it had at the beginning, as its specific gravity is continually diminishing. This difference may, it is true, be determined by calculation: but this would have occasioned such mathematical investigations, as must have rendered the use of this apparatus both troublesome and difficult. Mr Meusnier has remedied this inconvenience, by the following contrivance. A square rod of iron, 26, 27, Pl. VIII. Fig. 1. is raised perpendicular to the middle of the beam DE. This rod passes through a hollow box of brass 28, which opens, and may be filled with lead: and this box is made to slide along the rod, by means of a toothed pinion playing in a rack, so as to raise or lower the box, and to fix it at such places as is judged proper.

When the lever or beam DE stands horizon-



tal, this box gravitates to neither side. But, when the jar A sinks into the cistern LMNO, so as to make the beam incline to that side, it is evident the loaded box 28, which then passes beyond the centre of suspension, must gravitate to the side of the jar, and augment its pressure upon the included air. This is increased in proportion as the box is raised towards 27; because the same weight exerts a greater power in proportion to the length of the lever by which it acts. Hence, by moving the box 28 along the rod 26, 27, we can augment or diminish the correction it is intended to make upon the pressure of the jar: and both experience and calculation shew, that this may be made to compensate very exactly for the loss of weight in the jar at all degrees of pressure.

I have not hitherto explained the most important part of the use of this machine, which is the manner of employing it for ascertaining the quantities of the air or gas furnished during experiments. To determine this with the most rigorous precision, and likewise the quantity supplied to the machine from experiments, we fix to the arc which terminates the arm of the beam E, Pl. VIII. Fig. 1. the brass sector *lm*, divided into degrees and half degrees, which consequently moves in common with the beam: and the lowering of this end of the



beam is measured by the fixed index 29, 30, which has a Nonius giving hundredth parts of a degree, at its extremity 30.

The whole particulars of the different parts of the above described machine, are represented in Plate VIII. as follow.

Fig. 2. Is the flat chain invented by Mr Vaucanson, and employed for suspending the scale or bafon P, Fig. 1. But, as this lengthens or shortens according as it is more or less loaded, it would not have answered for suspending the jar A, Fig. 1.

Fig. 5. Is the chain *ikm*, which in Fig. 1. sustains the jar A. This is entirely formed of plates, of polished iron, interlaced into each other, and held together by iron pins. This chain does not lengthen in any sensible degree, by any weight it is capable of supporting.

Fig 6. The trivet, or three-branched stirrup, by which the jar A is hung to the balance, with the screw by which it is fixed in an accurately vertical position.

Fig. 3. The iron rod 26, 27, which is fixed perpendicular to the centre of the beam, with its box 28.

Fig. 7. & 8. The friction-wheels, with the plates of rock-crystal Z, as points of contact by which the friction of the axes of the lever of the balance is avoided.

Fig. 4. The piece of metal which supports the axis of the friction-wheels.

Fig. 9. The middle of the lever or beam, with the axis upon which it moves.

Fig. 10. The thermometer for determining the temperature of the air or gas contained in the jar.

When this gazometer is to be used, the cistern or external vessel, LMNO, Pl. VIII. Fig. 1. is to be filled with water to a determinate height, which should be the same in all experiments. The level of the water should be taken when the beam of the balance stands horizontal. This level, when the jar is at the bottom of the cistern, is increased by all the water which it displaces, and is diminished in proportion as the jar rises to its highest elevation. We next endeavour, by repeated trials, to discover at what elevation the box 28 must be fixed, to render the pressure equal in all situations of the beam. I should have said nearly, because this correction is not absolutely rigorous: and differences of a quarter, or even of half a line, are not of any consequence. This height of the box 28 is not the same for every degree of pressure; but varies according as this is of one, two, three, or more inches. All these should be registered with great order and precision.

We next take a bottle which holds eight or ten pints, the capacity of which is very accurately determined by weighing the water it is

capable of containing. This bottle is turned bottom upwards, full of water in the cistern of the pneumato-chemical apparatus GHIK, Fig. 1. and is set on its mouth upon the shelf of the apparatus, instead of the glass jar V, having the extremity 11 of the tube 7, 8, 9, 10, 11, inserted into its mouth. The machine is fixed at zero of pressure; and the degree marked by the index 30 upon the sector *ml* is accurately observed. Then, by opening the stop-cock 8, and pressing a little upon the jar A, as much air is forced into the bottle as fills it entirely. The degree marked by the index upon the sector is now observed; and we calculate what number of cubical inches correspond to each degree. We then fill a second and third bottle, and so on, in the same manner, with the same precautions, and even repeat the operation several times with bottles of different sizes, till at last, by accurate attention, we ascertain the exact gage or capacity of the jar A, in all its parts. But it is better to have it formed at first accurately cylindrical; by which we avoid these calculations and estimates.

The instrument I have been describing was constructed with great accuracy and uncommon skill by Mr Meignie junior, engineer and physical instrument-maker. It is a most valuable instrument, from the great number of purposes to

which it is applicable ; and, indeed, there are many experiments which are almost impossible to be performed without it. It becomes expensive, because, in many experiments, such as the formation of water and of nitric acid, it is absolutely necessary to employ two of the same machines. In the present advanced state of chemistry, very expensive and complicated instruments are become indispensably necessary, for ascertaining the analysis and synthesis of bodies, with the requisite precision as to quantity and proportion. It is certainly proper to endeavour to simplify these, and to render them less costly ; but this ought by no means to be attempted at the expence of their conveniency of application, and much less of their accuracy.

## S E C T. III.

*Some other Methods of measuring the Volume of Gasses.*

The gazometer described in the foregoing section is too costly and too complicated for being generally used in laboratories for measuring the gasses, and is not even applicable to every circumstance of this kind. In numerous series of experiments, more simple and more readily applicable methods must be employed. For this

purpose, I shall describe the means I used before I was in possession of a gazometer, and which I still use in preference to it, in the ordinary course of my experiments.

Suppose that, after an experiment, there is a residuum of gas, neither absorbable by alkali nor water, contained in the upper part of the jar AEF, Pl. IV. Fig. 3. standing on the shelf of a pneumato-chemical apparatus, of which we wish to ascertain the quantity ; we must first mark the height to which the mercury or water rises in the jar with great exactness, by means of slips of paper pasted in several parts round the jar. If we have been operating in mercury, we begin by displacing the mercury from the jar, by introducing water in its stead. This is readily done by filling a bottle quite full of water ; having stopped it with your finger, turn it up, and introduce its mouth below the edge of the jar ; then, turning down its body again, the mercury, by its gravity, falls into the bottle, and the water rises in the jar, and takes the place occupied by the mercury. When this is accomplished, pour so much water into the cistern ABCD as will stand about an inch over the surface of the mercury ; then pass the dish BC, Pl. V. Fig. 9. under the jar, and carry it to the water cistern, Fig. 1. and 2. We here exchange the gas into another jar, which has



been previously graduated in the manner to be afterwards described : and we thus judge of the quantity or volume of the gas by means of the degrees which it occupies in the graduated jar.

There is another method of determining the volume of gas, which may either be substituted in place of the one above described, or may be usefully employed as a correction or proof of that method. After the air or gas is exchanged from the first jar, marked with slips of paper, into the graduated jar, turn up the mouth of the marked jar, and fill it with water exactly to the marks EF, Pl. IV. Fig. 3. and by weighing the water, the volume of the air or gas it contained may be determined ; allowing one cubical foot or 1728 cubical inches, French measure, for each 70 *lbs.* French weight, or the same cubical volume, in English measure, for each 75.84 *lbs.* English Troy, of the water.

The manner of graduating jars for this purpose is very easy ; and we ought to be provided with several of different sizes, and even several of each size, in case of accidents. Take a tall, narrow, and strong glass jar, and, having filled it with water in the cistern, Pl. V. Fig. 1. place it upon the shelf ABCD. We ought always to use the same place for this operation, that the level of the shelf may be always exactly similar, by which almost the only error to which this pro-



cess is liable will be avoided. Then take a narrow mouthed phial holding exactly 5 oz. 2 *drams*, 12 *grs.* of water, which corresponds to 10 cubical inches. If you have not one exactly of this dimension, choose one a little larger, and diminish its capacity to the size requisite, by dropping in a little melted wax and rosin. This small phial serves the purpose of a standard for gaging the jars. Make the air contained in this bottle pass into the jar, and mark exactly the place to which the water has descended. Add another measure of air, and again mark the place of the water, and so on, till all the water be displaced. It is of great consequence, that, during the course of this operation, the bottle and jar be kept at the same temperature with the water in the cistern : and, for this reason, we must refrain, as much as possible, from keeping the hands upon either, or, if we suspect they have been heated, we must cool them again by means of the water in the cistern. The height of the barometer and thermometer during this experiment is of no consequence.

When the marks have been thus ascertained upon the jar for every ten cubical inches, we engrave a scale upon one of its sides, by means of a diamond pencil. Glass tubes are graduated in the same manner, for using in the mercurial apparatus, only they must be divided into

cubical inches, and tenths of a cubical inch. The bottle used for gaging these must hold 7 oz. 1 dr. 15 grs. of mercury, which exactly correspond to a cubical inch of that metal.

This method of determining the volume of air or gas, by means of a graduated jar, has the advantage of not requiring any correction for the difference of the height between the surface of the water within the jar, and in the cistern; but it requires corrections with respect to the height of the barometer and thermometer. But when we ascertain the volume of air by weighing the water which the jar is capable of containing, up to the marks EF, it is necessary to make a farther correction, for the difference between the surface of the water in the cistern, and the height to which it rises within the jar. This will be explained in the fifth section of this chapter.

#### S E C T. IV.

*Of the Method of separating the different Gasses from each other.*

As experiments often produce two, three, or more species of gas, it is necessary to be able to separate these from each other, that we may ascertain the quantity and species of each. Sup-

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pose that under the jar A, Pl. IV. Fig. 3. is contained a quantity of different gasses mixed together, and standing over mercury. We begin by marking with slips of paper, as before directed, the height at which the mercury stands within the glass; and then introduce about a cubical inch of water into the jar, which will swim over the surface of the mercury. If the mixture of gas contains any muriatic or sulphurous acid gas, a rapid and considerable absorption will instantly take place, from the strong tendency these two gasses have, especially the former, to combine with, or be absorbed by water. If the water only produces a slight absorption of gas, hardly equal to its own bulk, we conclude, that the mixture neither contains muriatic acid, sulphuric acid, or ammoniacal gas, but that it contains carbonic acid gas, of which water only absorbs about its own bulk. To ascertain this conjecture, introduce some solution of caustic alkali, and the carbonic acid gas will be gradually absorbed in the course of a few hours. It combines with the caustic alkali or potash: and the remaining gas is left almost perfectly free from any sensible residuum of carbonic acid gas.

After each experiment of this kind, we must carefully mark the height at which the mercury stands within the jar, by slips of paper pasted on, and varnished over when dry, that they may

not be washed off, when placed in the water apparatus. It is likewise necessary to register the difference between the surface of the mercury in the cistern, and that in the jar, and the height of the barometer and thermometer, at the end of each experiment.

When all the gas or gasses absorbable by water and potash are absorbed, water is admitted into the jar to displace the mercury: and, as is described in the preceding section, the mercury in the cistern is to be covered by one or two inches of water. After this, the jar is to be transported, by means of the flat dish BC, Pl. V. Fig. 9. into the water apparatus; and the quantity of gas remaining is to be ascertained by changing it into a graduated jar. After this, small trials of it are to be made by experiments in little jars, to ascertain nearly the nature of the gas in question. For instance, into a small jar full of the gas, Fig. 8. Pl. V. a lighted taper is introduced. If the taper is not immediately extinguished, we conclude the gas to contain oxygen gas: and, in proportion to the brightness of the flame, we may judge if it contains less or more oxygen gas than atmospheric air contains. If, on the contrary, the taper be instantly extinguished, we have strong reason to presume that the residuum is chiefly composed of azotic gas. If, upon the approach of the taper, the gas takes fire, and burns quietly at the

surface with a white flame, we conclude it to be pure hydrogen gas. If this flame is blue, we judge it consists of carbonated hydrogen gas; and, if it takes fire with a sudden deflagration, that it is a mixture of oxygen and hydrogen gas. If, again, upon mixing a portion of the residuum with oxygen gas, red fumes are produced, we conclude that it contains nitrous gas.

These preliminary trials give some general knowledge of the properties of the gas, and nature of the mixture, but are not sufficient to determine the proportions and quantities of the several gasses of which it is composed. For this purpose, all the methods of analysis must be employed; and, to direct these properly, it is of great use to have a previous approximation by the above methods. Suppose, for instance, we know that the residuum consists of oxygen and azotic gas mixed together, put a determinate quantity, 100 parts, into a graduated tube of ten or twelve lines diameter, introduce a solution of sulphuret of potash in contact with the gas, and leave them together for some days; the sulphuret absorbs the whole oxygen gas, and leaves the azotic gas pure.

If it is known to contain hydrogen gas, a determinate quantity is introduced into Volta's eudiometer, along with a known proportion of oxygen gas. These are deflagrated together by means of the electrical spark. Fresh portions of

oxygen gas are successively added, till no farther deflagration takes place, and till the greatest possible diminution is produced. By this process, water is formed, which is immediately absorbed by the water of the apparatus. But, if the hydrogen gas contain carbon, carbonic acid is formed at the same time, which is not absorbed so quickly. The quantity of this is readily ascertained by assisting its absorption, by means of agitation. If the residuum contains nitrous gas, by adding oxygen gas, with which it combines into nitric acid, we can very nearly ascertain its quantity, from the diminution produced by this mixture.

I confine myself to these general examples, which are sufficient to give an idea of this kind of operations. A whole volume would not serve to explain every possible case. It is necessary to become familiar with the analysis of gasses by long experience. We must even acknowledge that they mostly possess such powerful affinities to each other, that we are not always certain of having separated them completely. In these cases, we must vary our experiments in every possible point of view ; adding new agents to the combination, and keeping out others ; and must continue our trials, till we are certain of the truth and exactitude of our conclusions.

SECT.



## S E C T. V.

*Of the necessary Corrections upon the Volume of the Gasses, according to the Pressure of the Atmosphere.*

All elastic fluids are compressible or condensible, in proportion to the weight with which they are loaded. Perhaps this law, which is ascertained by general experience, may suffer some irregularity when these fluids are under a degree of condensation almost sufficient to reduce them to the liquid state, or when either in a state of extreme rarefaction or condensation. But we seldom approach either of these limits with most of the gasses which we submit to our experiments. I understand this proposition of gasses being compressible, in proportion to their superincumbent weights, as follows.

A barometer, which is an instrument generally known, is, properly speaking, a species of syphon, ABCD, Pl. XII. Fig. 16. whose leg AB is filled with mercury, while the leg CD is full of air. If we suppose the branch CD indefinitely continued till it equals the height of our atmosphere, we can readily conceive that the barometer is, in reality, a sort of balance, in which

a column of mercury stands in equilibrium with a column of air of the same weight. But it is unnecessary to prolongate the branch CD to such a height; as it is evident that the barometer being immersed in air, the column of mercury AB will be equally in equilibrium with a column of air of the same diameter, though the leg CD be cut off at C, and the part CD be taken away altogether.

The medium height of mercury in equilibrium with the weight of a column of air, from the highest part of the atmosphere to the surface of the earth, is about twenty-eight French or 29.85 English inches in the lower parts of the city of Paris: or, in other words, the air at the surface of the earth at Paris, is usually pressed upon by a weight equal to that of a column of mercury twenty-eight inches in height. I must be understood in this way, in the several parts of this publication, when talking of the different gasses; as, for instance, when the cubical foot of oxygen gas is said to weigh 538.45 grs. under 29.85 inches pressure. The height of this column of mercury, supported by the pressure of the air, diminishes in proportion as we are elevated above the surface of the earth, or rather above the level of the sea; because the mercury can only form an equilibrium with the column of air which is above it, and is not in the smallest degree affected by the air which is below its level.

In what ratio does the mercury in the barometer descend in proportion to its elevation? or, which is the same thing, according to what law or ratio do the several strata of the atmosphere decrease in density? this question, which has exercised the ingenuity of natural philosophers during the last century, is considerably elucidated by the following experiment.

If we take the glass syphon ABCDE, Pl. XII. Fig. 17. shut at E, and open at A, and introduce a few drops of mercury, so as to intercept the communication of air between the leg AB and the leg BE, it is evident, that the air contained in BCDE is pressed upon, in common with the whole surrounding air, by a weight or column of air equal to 29.85 inches of mercury. But, if we pour 29.85 inches of mercury into the leg AB, it is plain that the air in the branch BCDE will then be pressed upon by a weight equal to twice 29.85 inches of mercury, or twice the weight of the atmosphere. And experience shews, that in this case, the included air, instead of filling the tube from B to E, only occupies from C to E, or exactly one half of the space it filled before. If to this first column of mercury we add two other portions of 29.85 inches each, in the branch AB, the air, in the branch BCDE, will be pressed upon by four times the weight of the atmosphere, or four times the weight of 29.85 inches of mercury. And it will then only fill the

space from D to E, or exactly one quarter of the space it occupied at the commencement of the experiment. From these experiments, which may be infinitely varied, it has been deduced, as a general law of nature, which seems applicable to all permanently elastic fluids, that they diminish in volume directly in proportion to the weights with which they are pressed; or, in other words, “*the volume of all elastic fluids is in the inverse ratio of the weight by which they are compressed.*”

The experiments which have been made for measuring the heights of mountains by means of the barometer, confirm the truth of these deductions: and, even supposing them in some degree inaccurate, these differences are so extremely small, that they may be reckoned as nothing in chemical experiments. When this law of the compression of elastic fluids is once well understood, it becomes easily applicable to the corrections, necessary in pneumato-chemical experiments, upon the volume of gas, in relation to its pressure. These corrections are of two kinds, the one relative to the variations of the barometer, and the other for the column of water or mercury contained in the jars. I shall endeavour to explain these by examples, beginning with the most simple case.

Suppose that 100 cubical inches of oxygen gas are obtained at inches 54.5° of the thermo-

F f t

meter, and at 30.37 inches of the barometer ; it is required to know what volume the 100 cubical inches of gas would occupy, under the pressure of 29.85 inches, and what is the exact weight of the 100 inches of oxygen gas ? Let the unknown volume, or the number of inches this gas would occupy at 29.85 inches of the barometer, be expressed by  $x$  ; and, since the volumes are in the inverse ratio of their superincumbent weights, we have the following statement : 100 cubical inches is to  $x$ , inversely as 30.37 inches of pressure is to 29.85 inches ; or directly  $29.85 : 30.37 :: 100 : x = 101.741$ —cubical inches, at 29.85 inches barometrical pressure. That is to say, the same gas or air, which at 30.37 inches of the barometer, occupies 100 cubical inches of volume, will occupy 101.741 cubical inches, when the barometer is at 29.85 inches. It is equally easy to calculate the weight of this gas, occupying 100 cubical inches, under 30.37 inches of barometrical pressure ; for, as it corresponds to 101.741 cubical inches at the pressure of 29.85 ; and as, at this pressure, and at  $54.5^{\circ}$  of temperature, each cubical inch of oxygen gas weighs 0.311023 gr. it follows, that 100 cubical inches, under 30.37 barometrical pressure, must weigh 31.644 grains. This conclusion might have been formed more directly ; as, since the volume of elastic fluids is in the inverse ratio of their compression, their weights



must be in the direct ratio of the same compression. Hence, since 100 cubical inches weigh 31.1023 grains, under the pressure of 29.85 inches, we have the following statement to determine the weight of 100 cubical inches of the same gas at 30.37 barometrical pressure;  $29.85 : 31.1023 :: 30.37 : x$ , the unknown quantity, = 31.644.

The following case is more complicated. Suppose the jar A, Pl. XII. Fig. 18. to contain a quantity of gas in its upper part ACD, the rest of the jar below CD being full of mercury, and the whole standing in the mercurial basin or reservoir GHIK, filled with mercury up to EF, and that the difference between the surface CD of the mercury in the jar, and EF, that in the cistern, is six inches, while the barometer stands at 27.5 inches. It is evident from these data, that the air contained in ACD is pressed upon by the weight of the atmosphere, diminished by the weight of the column of mercury CE, or by  $27.5 - 6 = 21.5$  inches of barometrical pressure. This air is therefore less compressed than the atmosphere, at the mean height of the barometer; and consequently occupies more space than it would occupy at the mean pressure; the difference being exactly proportional to the difference between the compressing weights. If, then, upon measuring the space ACD, it is found to be 120 cubical inches, it must be re-



duced to the volume which it would occupy under the mean pressure of 29.85 inches. This is done by the following statement : 120 :  $x$ , the unknown volume :: 21.5 : 29.85 inversely ; this gives  $x = \frac{120 \times 21.5}{29.85} = 86.432$  cubical inches.

In these calculations, we may either reduce the height of the mercury in the barometer, and the difference of level in the jar and bason, to lines, or to decimal fractions of the inch : but I prefer the latter, as it is more readily calculated. As, in these operations, which frequently recur, it is of great use to have means of abbreviation, I have given a table in the appendix, for reducing lines and fractions of lines into decimal fractions of the inch.

In experiments performed in the water apparatus, we must make similar corrections to procure rigorously exact results, by taking into account, and making allowance for, the difference of height of the water within the jar, above the surface of the water in the cistern. But, as the pressure of the atmosphere is expressed in inches and lines of the mercurial barometer, and, as homogeneous quantities only can be calculated together, we must reduce the observed inches and lines of water into correspondent heights of the mercury. I have given a table in the appendix for this conversion, upon the supposition, that mercury is 13.5681 times heavier than water.

SECT.

## SECT. VI.

*Of Corrections relative to the Degrees of the Thermometer.*

In ascertaining the weight of gasses besides reducing them to a mean of barometrical pressure, as directed in the preceding section, we must likewise reduce them to a standard thermometrical temperature; because, all elastic fluids being expanded by heat, and condensed by cold, their weight in any determinate volume is thereby liable to considerable alterations. As the temperature of  $54.5^{\circ}$  is a medium between the heat of summer and the cold of winter, being the temperature of subterraneous places, and that which is most easily approached to at all seasons, I have chosen that degree as a mean to which I reduce air or gas in this species of calculation.

Mr. de Luc found that atmospheric air was increased  $\frac{1}{215}$  part of its bulk, by each degree of a mercurial thermometer, divided into 81 degrees, between the freezing and boiling points. This gives  $\frac{1}{21.1}$  part for each degree of

Reaumur's thermometer, which is divided into 80 degrees between these two points; or  $\frac{1}{474.75}$  part of each degree of Fahrenheit's scale, which is divided into 180 degrees between the same fixed points. The experiments of Mr. Monge seem to make this dilation less for hydrogen gas, which he thinks is only dilated  $\frac{1}{138}$  for each degree of Reaumur, or  $\frac{1}{405}$  for each of Fahrenheit's degrees. We have not any exact experiments hitherto published respecting the ratio of dilatation of the other gasses. But, from the trials which have been made, their dilatation seems to differ little from that of atmospheric air. Hence I may take for granted, till farther experiments give us better information upon this subject, that atmospherical air is dilated  $\frac{1}{218}$  part, and hydrogen gas  $\frac{1}{198}$  part for each degree of Reaumur's thermometer, or that atmospheric air is dilated  $\frac{1}{472.5}$  part, and hydrogen gas  $\frac{1}{427.5}$  part for each degree on the scale of Fahrenheit; but as there is still great uncertainty upon this point, we ought always to operate in a temperature as near as possible to the standard of  $54.5^{\circ}$ . By this means any errors in correcting the weight or volume of gasses by reducing them to the common standard, will become of little moment.

The calculation for this correction is extremely easy. Divide the observed volume of

air by 210, for Reaumur's scale, or 472.5 for that of Fahrenheit, and multiply the quotient by the degree of temperature above or below  $54.5^{\circ}$ . This correction is negative when the actual temperature is above the standard, and positive when below. By the use of logarithmetical tables, this calculation is much facilitated.

## S E C T. VII.

*Example for calculating the Corrections relative to the Variations of Pressure and Temperature.*

## C A S E.

In the jar A, Pl. IV. Fig. 3. standing in a water apparatus, are contained 353 cubical inches of air. The surface of the water within the jar at EF is  $4\frac{1}{2}$  inches above the water in the cistern: the barometer is at 27 inches  $9\frac{1}{2}$  lines, and the thermometer at  $65.75^{\circ}$ . Having burned a quantity of phosphorus in the air, by which concrete phosphoric acid is produced; the air after the combustion occupies 295 cubical inches; the water within the jar stands 7 inches above that in

the cistern, the barometer is at 27 inches  $9\frac{1}{4}$  lines, and the thermometer at  $68^{\circ}$ . It is required from these data to determine the actual volume of air, before and after combustion, and the quantity absorbed during the process.

*Calculation before Combustion.*

The air in the jar before combustion was 353 cubical inches: but it was only under a barometrical pressure of 27 inches  $9\frac{1}{2}$  lines; which, reduced to decimal fractions, by Tab. I. of the Appendix, gives 27.79167 inches: and from this we must deduct the difference of  $4\frac{1}{2}$  inches of water, which, by Tab. II. corresponds to 0.33166 inches of the barometer. Hence the real pressure of the air in the jar is 27.46001. As the volume of elastic fluids diminishes in the inverse ratio of the compressing weights, we have the following statement, to reduce the 353 inches to the volume the air would occupy at 28 inches barometrical pressure.

$353 : x$ , the unknown volume  $:: 27.46001 : 28$ .  
Hence,  $x = \frac{353 \times 27.46001}{28} = 346.192$  cubical inches, which is the volume the same quantity

air would have occupied at 28 inches of the barometer.

The 472.5th part of this corrected volume is .73247, which, for the 11.25 degrees of temperature above the standard, gives 8.24 cubical inches; and, as this correction is subtractive, the real corrected volume of the air before combustion is 337.952 inches.

*Calculation after Combustion.*

By a similar calculation upon the volume of air after combustion, we find its barometrical pressure  $27.77083 - 0.51593 = 27.25490$ . Hence, to have the volume of air under the pressure of 28 inches,  $295 : x :: 27.77083 : 28$  inversely; or,  $x = \frac{295 \times 27.25490}{28} = 287.150$ . The 472.5th part of this corrected volume is .61, which, multiplied by 13.5 degrees of thermometrical difference, gives the subtractive correction for temperature, 8.235, leaving the actual corrected volume of air after combustion 278.915 inches.



*Result.*

The corrected volume before combustion,	-	-	337.952
Ditto remaining after combustion,	-	-	278.915
			<hr/>
Volume absorbed during combustion,			59.037

## S E C T. VIII.

*Method of determining the absolute Gravity of the different Gasses.*

Take a large balloon A, Pl. V. Fig. 10. capable of holding 17 or 18 pints, or about half a cubical foot, having the brass cap *b c d e* strongly cemented to its neck, and to which the tube and stop-cock *f g* is fixed by a tight-screw. This apparatus is connected by the double screw, represented separately at Fig. 12 to the jar BCD, Fig. 10. which must be some pints larger in dimensions than the balloon. This jar is open at top, and is furnished with the brass cap *h i*, and the stop-cock *l m*. One of these stop-cocks is represented separately at Fig 11.

We first determine the exact capacity of the balloon by filling it with water, and weighing it both full and empty. When emptied of water, it is dried with a cloth introduced through its neck *de*: and the last remains of moisture are removed by exhausting it once or twice in an air-pump.

When the weight of any gas is to be ascertained, this apparatus is used as follows. Fix the balloon *A* to the plate of an air-pump, by means of the screw of the stop-cock *fg*, which is left open. The balloon is to be exhausted as completely as possible, observing carefully the degree of exhaustion by means of the barometer attached to the air-pump. When the vacuum is formed, the stop-cock *fg* is shut, and the weight of the balloon determined with the most scrupulous exactitude. It is then fixed to the jar *BCD*, which we suppose placed in water in the shelf of the pneumato-chemical apparatus Fig. 1.; the jar is to be filled with the gas we mean to weigh; and then, by opening the stop-cocks *fg* and *lm*, the gas ascends into the balloon, whilst the water of the cistern rises at the same time into the jar. To avoid very troublesome corrections, it is necessary, during this first part of the operation, to sink the jar in the cistern till the surfaces of the water within and without the jar exactly correspond. The stop-

cocks are again shut : and the balloon, being unscrewed from its connection with the jar, is to be carefully weighed. The difference between this weight and that of the exhausted balloon, is the precise weight of the air or gas contained in the balloon. Multiply this weight by 1728, the number of cubical inches in a cubical foot, and divide the product by the number of cubical inches contained in the balloon, the quotient is the weight of a cubical foot of the gas or air submitted to experiment.

Exact account must be kept of the barometrical height and the temperature of the thermometer during the above experiment ; and from these the resulting weight of a cubical foot is easily corrected to the standards of 28 inches pressure, and  $54.5^{\circ}$  temperature, as directed in the preceding section. The small portion of air remaining in the balloon after forming the vacuum, must likewise be attended to : and this is easily determined by the barometer attached to the air-pump. If that barometer, for instance, remains at the hundredth part of the height it stood at before the vacuum was formed, we conclude that one hundredth part of the air originally contained, remains in the balloon, and consequently that only  $\frac{99}{100}$  of gas was introduced from the jar into the balloon.

## C H A P    III.

*Description of the Calorimeter, or apparatus for measuring Caloric.*

THE calorimeter, or apparatus for measuring the relative quantities of heat contained in bodies, was described by Mr de la Place and me in the Memoirs of the Academy for 1780, p. 355 : and from that Essay the materials of this chapter are extracted.

If, after having cooled any body to the freezing point, it be exposed in an atmosphere of  $88.25^{\circ}$ , the body will gradually become heated, from the surface inwards, till at last it acquire the same temperature with the surrounding air. But, if a piece of ice be placed in the same situation, the circumstances are quite different. It does not approach in the smallest degree towards the temperature of the circumambient air ; but remains constantly at  $32^{\circ}$ , or the temperature of melting ice, till the last portion of ice be completely melted.

This phenomenon is readily explained ; as, to melt ice, or reduce it to water, it requires to be combined with a certain portion of caloric,

the whole caloric attracted from the surrounding bodies, is arrested or fixed at the surface or external layer of ice which it is employed to dissolve, and combines with it to form water ; the next quantity of caloric combines with the second layer to dissolve it into water, and so on successively till the whole ice be dissolved, or converted into water, by combination with caloric : the very last atom still remaining at its former temperature, because the caloric could never penetrate so far, while any intermediate ice remained to melt, or to combine with.

Upon these principles, if we conceive a hollow sphere of ice at the temperature of  $32^{\circ}$  placed in an atmosphere of  $54.5^{\circ}$ , and containing a substance at any degree of temperature above freezing ; it follows, that the heat of the external atmosphere cannot penetrate into the internal hollow of the sphere of ice ; and, that the heat of the body which is placed in the hollow of the sphere, cannot penetrate outwards beyond it, but will be stopped at the internal surface, being continually employed to melt successive layers of ice, until the temperature of the body be reduced to  $32^{\circ}$  by having all its superabundant caloric, above that temperature, carried off to melt the ice. If the whole water, formed within the sphere of ice during the reduction of the temperature of the included body to  $32^{\circ}$ , be carefully collected, the weight

of the water will be exactly proportional to the quantity of caloric lost by the body, in passing from its original temperature to that of melting ice; for it is evident, that a double quantity of caloric would have melted twice the quantity of ice. Hence the quantity of ice melted is a very exact measure of the proportional quantity of caloric employed to produce that effect, and consequently of the quantity lost by the only substance that could possibly have supplied it.

I have made this supposition, of what would take place in a hollow sphere of ice, for the purpose of more readily explaining the method used in this species of experiment, which was first conceived by Mr de la Place. It would be difficult to procure such spheres of ice, and inconvenient to make use of them when got; but, by means of the following apparatus, we have remedied that defect. I acknowledge the name of Calorimeter, which I have given it, as derived partly from Greek and partly from Latin, is in some degree open to criticism. But, in matters of science, a slight deviation from strict etymology, for the sake of giving distinctness of idea, is excusable: and I could not derive the name entirely from Greek without approaching too near to the names of known instruments employed for other purposes.

The calorimeter is represented in Pl. VI. It is shewn in perspective at Fig. 1. and its interior



structure is engraved at Fig. 2 and 3.; the former being horizontal, and the latter a perpendicular section. Its capacity or cavity is divided into three parts, which, for better distinction, I shall name the interior, middle, and external cavities. The interior cavity *ffff*, Fig. 4. into which the substances submitted to experiment are put, is composed of a grating or cage of iron wire, supported by several iron bars. Its opening, or mouth, LM, is covered by the lid HG, which is composed of the same materials. The middle cavity *b b b b*, Fig 2. and 3. is intended to contain the ice which surrounds the interior cavity, and which is intended to be melted by the caloric of the substances employed in the experiment. The ice is supported by the grate *m m* at the bottom of the cavity, under which is placed the sieve *n n*. These two are represented separately in Figures 5. and 6.

In proportion as the ice contained in the middle cavity is melted, by the caloric disengaged from the body placed in the interior cavity, the water runs through the grate and sieve, and falls through the conical funnel *c c d*, Fig. 3 and the tube *x y*, into the receiver F, Fig. 1. This water may be retained or let out at pleasure, by means of the stop-cock *u*. The external cavity *a a a a*, Fig. 2. and 3. is filled with ice, to prevent any effect upon the ice in the middle ca-

vity from the heat of the surrounding air; and the water produced from it is carried off through the pipe ST, which shuts by means of the stop-cock *r*. The whole machine is covered by the lid FF, Fig. 7, which is made of tin, and painted with oil colour, to prevent rust.

When this machine is employed, the middle cavity *b b b b*, Fig. 2 and 3. the lid GH, Fig. 4. of the interior cavity, the external cavity *a a a a*, Fig. 2. and 3. and the general lid FF, Fig. 7. are all filled with pounded ice, well rammed, so that no void spaces remain, and the ice of the middle cavity is allowed to drain. The machine is then opened, and the substance submitted to experiment being placed in the interior cavity, it is instantly closed. After waiting till the included body is completely cooled to the freezing point, and the whole melted ice has drained from the middle cavity, the water collected in the vessel F, Fig. 1. is accurately weighed. The weight of the water produced during the experiment is an exact measure of the caloric disengaged during the cooling of the included body; as this substance is evidently in a similar situation with the one formerly mentioned as included in a hollow sphere of ice. The whole caloric disengaged from the included body is stopped by the ice in the middle cavity: and that ice is preserved from being affected by any other

H h h

heat by means of the ice contained in the general lid, Fig. 7. and in the external cavity. Experiments of this kind generally last from fifteen to twenty hours: but they are sometimes accelerated by covering up the substance in the interior cavity with well drained ice, which hastens its cooling.

The substances to be operated upon are placed in the thin iron bucket, Fig. 8. the cover of which has an opening fitted with a cork, into which a small thermometer is fixed. When we use acids, or other fluids capable of injuring the metal of the instruments, they are contained in the matrafs, Fig. 10. which has a similar thermometer in a cork fitted to its mouth, and which stands in the interior cavity, upon the small cylindrical support RS, Fig. 10.

It is absolutely requisite, that there be no communication between the external and middle cavities of the calorimeter; otherwise the ice melted by the influence of the surrounding air, in the external cavity, would mix with the water produced from the ice of the middle cavity, which would no longer be a measure of the caloric lost by the substance submitted to experiment.

When the temperature of the atmosphere is only a few degrees above the freezing point, its heat can hardly reach the middle cavity, being arrested by the ice of the cover, Fig. 7. and of the external cavity. But, if the temperature of

the air be under the degree of freezing, it might cool the ice contained in the middle cavity, by causing the ice in the external cavity to fall, in the first place, below  $32^{\circ}$ . It is therefore essential, that this experiment be carried on in a temperature somewhat above freezing. Hence, in time of frost, the calorimeter must be kept in an apartment carefully heated. It is likewise necessary, that the ice employed be not under  $32^{\circ}$ ; for which purpose it must be pounded, and spread out thin for some time, in a place where the temperature is higher.

The ice of the interior cavity always retains a certain quantity of water adhering to its surface, which may be supposed to belong to the result of the experiment. But as, at the beginning of each experiment, the ice is already saturated with as much water as it can contain, if any of the water produced by the caloric should remain attached to the ice, it is evident, that very nearly an equal quantity of what adhered to it before the experiment must have run down into the vessel F in its stead; for the inner surface of the ice in the middle cavity is very little changed during the experiment.

By any contrivance that could be devised, we could not prevent the access of the external air into the interior cavity, when the atmosphere was at  $52^{\circ}$  or  $54^{\circ}$ . The air confined in the cavity being in that case specifically heavier than

the external air, escapes downwards through the pipe  $x y$ , Fig. 3. and is replaced by the warmer external air, which, giving out its caloric to the ice, becomes heavier, and sinks in its turn. Thus a current of air is formed through the machine, which is the more rapid in proportion as the external air exceeds the internal in temperature. This current of warm air must melt a part of the ice, and injure the accuracy of the experiment. We may, in a great degree, guard against this source of error, by keeping the stopcock  $u$  continually shut. But it is better to operate only when the temperature of the external air does not exceed  $39^{\circ}$ , or at most  $41^{\circ}$ ; for we have observed, that, in this case, the melting of the interior ice by the atmospheric air is perfectly insensible; so that we may answer for the accuracy of our experiments upon the specific heat of bodies to a fortieth part.

We have caused two of the above described machines to be made. One, which is intended for such experiments as do not require the interior air to be renewed, is formed precisely according to the description here given. The other, which answers for experiments upon combustion, respiration, &c. in which fresh quantities of air are indispensibly necessary, differs from the former in having two small tubes in the two lids, by which a current of atmospheric air may be blown into the interior cavity of the machine.



It is extremely easy, with this apparatus, to determine the phenomena which occur in operations where caloric is either disengaged or absorbed. If we wish, for instance, to ascertain the quantity of the caloric which is disengaged from a solid body, in cooling a certain number of degrees; let its temperature be first raised to  $212^{\circ}$ : it is then placed in the interior cavity *ffff*, Fig. 2 and 3. of the calorimeter, and allowed to remain till we are certain that its temperature is reduced to  $32^{\circ}$ : the water produced by melting the ice during its cooling, is collected, and carefully weighed: and this weight, divided by the volume of the body submitted to experiment, and multiplied into the degrees of temperature which it had above  $32^{\circ}$  at the commencement of the experiment, gives the proportion of what the English philosophers call specific heat.

Fluids are contained in proper vessels, whose specific heat has been previously ascertained; and are operated upon in the machine in the same manner as directed for solids; taking care to deduct, from the quantity of water melted during the experiment, the proportion which belongs to the specific heat of the containing vessel.

If the quantity of caloric disengaged during the combination of different substances is to be determined, these substances are to be previously reduced to the freezing degree by keeping them



a sufficient time surrounded with pounded ice: The mixture is then to be made in the inner cavity of the calorimeter, in a proper vessel likewise reduced to  $32^{\circ}$ ; and they are kept inclosed till the temperature of the combination has returned to the same degree. The quantity of water produced is a measure of the caloric disengaged during the combination.

To determine the quantity of caloric disengaged during combustion, and during animal respiration, the combustible bodies are burnt, or the animals are made to breathe, in the interior cavity, and the water produced is carefully collected. Guinea-pigs, which resist the effects of cold extremely well, are well adapted for this experiment. As the continual renewal of air is absolutely necessary in such experiments, we blow fresh air into the interior cavity of the calorimeter by means of a pipe destined for that purpose; and allow it to escape through another pipe of the same kind: and that the heat of this air may not produce errors in the results of the experiments, the tube, which conveys it into the machine, is made to pass through pounded ice, that it may be reduced to  $32^{\circ}$  before it arrives at the calorimeter. The air which escapes, must likewise be made to pass through a tube surrounded with ice, included in the interior cavity of the machine: and the water which is there produced must make a part of what is collected;

because the caloric disengaged from this air is part of the product of the experiment.

It is somewhat more difficult to determine the specific caloric contained in the different gasses, on account of their small degree of density; for, if they are only placed in the calorimeter in vessels like other fluids, the quantity of ice melted is so small, that the result of the experiment becomes at best very uncertain. For this species of experiment we have contrived to make the air pass through two metallic worms, or spiral tubes. One of these, through which the air passes, and becomes heated in its way to the calorimeter, is contained in a vessel full of boiling water: and the other, through which the air circulates within the calorimeter to disengage its caloric, is placed in the interior cavity, *ffff*, of that machine. By means of a small thermometer placed at one end of the second worm, the temperature of the air, as it enters the calorimeter is determined: and its temperature in getting out of the interior cavity, is found by another thermometer placed at the other end of the worm. By this contrivance we are enabled to ascertain the quantity of ice melted by determinate quantities of air or gas, while losing a certain number of degrees of temperature, and, consequently, to determine their several degrees of specific caloric. The same apparatus, with some particular precautions, may be employed

to ascertain the quantity of caloric disengaged by the condensation of the vapours of different liquids.

The various experiments which may be made with the calorimeter, do not afford absolute conclusions, but only give us the measure of relative quantities. We have therefore to fix a unit, or standard point, from whence to form a scale of the several results. The quantity of caloric necessary to melt a pound of ice has been chosen as this unit: and, as it requires a pound of water of the temperature of  $167^{\circ}$  to melt a pound of ice, the quantity of caloric expressed by our unit or standard point is what raises a pound of water from  $32^{\circ}$  to  $167^{\circ}$ . When this unit is once determined, we have only to express the quantities of caloric disengaged from different bodies, by cooling a certain number of degrees, in analogous values. The following is an easy mode of calculation for this purpose, applied to one of our earliest experiments.

We took 7 *lb.* 11 *oz.* 2 *grs* 36 *grs.* of plate-iron, cut into narrow slips, and rolled up; or, expressing the quantity in decimals, 7.7070319 *lbs.* These being heated in a bath of boiling water to about  $207.5^{\circ}$ , were quickly introduced into the interior cavity of the calorimeter. At the end of eleven hours, when the whole quantity of water melted from the ice had thoroughly drained off, we found that 1.109795 pounds

pounds of ice were melted. Hence, the caloric disengaged from the iron by cooling  $175.5^{\circ}$  having melted 1.109795 pounds of ice, how much would have been melted by cooling  $135^{\circ}$ ? This question gives the following statement in direct proportion,  $175.5 : 1.109795 :: 135 : x = 0.85384$ . Dividing this quantity by the weight of the whole iron employed, viz. 7.7070319, the quotient 0.1109 is the quantity of ice which would have been melted by one pound of iron while cooling through 135 degrees of temperature.

Fluid substances, such as sulphuric and nitric acids, &c. are contained in a matrafs, Pl. VI. Fig. 9. having a thermometer adapted to the cork, with its bulb immersed in the liquid. The matrafs is placed in a bath of boiling water; and when, from the thermometer, we judge the liquid is raised to a proper temperature, the matrafs is placed in the calorimeter. The calculation of the products, to determine the specific caloric of these fluids, is made as above directed, taking care to deduct from the water obtained, the quantity which would have been produced by the matrafs alone, which must be ascertained by a previous experiment. The table of the results obtained by these experiments is omitted, because not yet sufficiently complete; different circumstances having occasioned the series to be interrupted. It is not, however, lost sight of; and we are less or more employed upon the subject every winter.

## C H A P. IV.

*Of Mechanical Operations for the Division of Bodies.*

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S E C T. I.*Of Trituration, Levigation, and Pulverization.*

THESE are, properly speaking, only preliminary mechanical operations for dividing and separating the particles of bodies, and reducing them into very fine powder. These operations can never reduce substances into their primary, or elementary and ultimate particles. They do not even destroy the aggregation of bodies; for every particle, after the most accurate trituration, forms a small whole, resembling the original mass from which it was divided. The real chemical operations, on the contrary, such as solution, destroy the aggregation of bodies, and separate their constituent and integrant particles from each other.

Brittle substances are reduced to powder by means of pestles and mortars. These are of brass or iron, Pl. I. Fig. 1. ; of marble or granite, Fig. 2. ; of *lignum vitæ*, Fig. 3. ; of glass, Fig. 4. ; of agate, Fig. 5. ; or of porcelain, Fig. 6. The pestles for each of these are represented in the plate, immediately below the mortars to which they respectively belong ; and are made of hammered iron or brass, of wood, glass, porcelain, marble, granite, or agate, according to the nature of the substances they are intended to triturate. In every laboratory, it is requisite to have an assortment of these utensils, of various sizes and kinds. Those of porcelain and glass can only be used for rubbing substances to powder, by a dextrous use of the pestle round the sides of the mortar ; as it would be easily broken by reiterated blows of the pestle.

The bottom of mortars ought to be made in form of a hollow sphere, and their sides should have such a degree of inclination as to make the substances they contain fall back to the bottom when the pestle is lifted, but not so perpendicular as to collect them too much together ; otherwise too large a quantity would get below the pestle, and prevent its operation. For this reason, likewise, too large a quantity of the substance to be powdered ought not to be put into the mortar at one time : and we must from



time to time get rid of the particles already reduced to powder, by means of sieves to be afterwards described.

The most usual method of levigation is by means of a flat table ABCD, Pl. I. Fig. 7. made of porphyry, or some other stone of similar hardness. On this the substance to be reduced to powder is spread; and is then bruised and rubbed by a muller M, of the same hard materials, the bottom of which is made a small portion of a large sphere. And, as the muller tends continually to drive the substances towards the sides of the table, a thin flexible knife, or spatula, of iron, horn, wood, or ivory, is used for bringing them back to the middle of the stone.

In large works, this operation is performed by means of large rollers of hard stone, which turn upon each other, either horizontally, in the way of corn-mills, or by one vertical roller turning upon a flat-stone. In the above operations, it is often requisite to moisten the substances a little, to prevent the fine powder from flying off.

There are many bodies which cannot be reduced to powder by any of the foregoing methods; such are fibrous substances, as woods, such substances as are tough and elastic, as the horns of animals, elastic gum, &c. and the malleable metals, which flatten under the pestle, instead of being reduced to powder. For redu-

cing the woods to powder, rasps, as in Pl. I. Fig. 8. are employed. Files of a finer kind are used for horn; and still finer, Pl. I. Fig. 9. and 10. for metals.

Some of the metals, though not brittle enough to powder under the pestle, are too soft to be filed, as they clog the file, and prevent its operation. Zinc is one of these: but it may be powdered, when hot, in a heated iron mortar; or it may be rendered brittle, by alloying it with a small quantity of mercury. One or other of these methods is used by fire-work makers for producing a blue flame by means of zinc. Metals may be reduced into grains, by pouring them when melted into water; which method serves very well when they are not wanted in fine powder.

Fruits, potatoes, &c, of a pulpy and fibrous nature, may be reduced to pulp by means of the grater, Pl. I. Fig. 11.

The choice of the different substances of which these instruments are made, is a matter of importance. Brass or copper are unfit for operations upon substances to be used as food or in pharmacy; and marble or metallic instruments must not be used for acid substances. Hence mortars of very hard wood, and those of porcelain, granite, or glass, are of great utility in many operations.

## S E C T. II.

*Of Sifting and Washing Powdered Substances.*

None of the mechanical operations, employed for reducing bodies to powder, are capable of producing it of an equal degree of fineness throughout : The powder obtained by the longest and most accurate trituration being still an assemblage of particles of various sizes. The coarser of these are removed, so as only to leave the finer and more homogeneous particles, by means of sieves, Pl. I. Fig. 12, 13, 14, 15. of different finenesses, adapted to the particular purposes they are intended for. All the powdered matter which is larger than the interstices of the sieve remains behind, and is again submitted to the pestle, while the finer passes through. The sieve Fig. 12. is made of hair-cloth, or of silk-gauze : and the one represented Fig. 13. is of parchment pierced with round holes of a proper size. This latter is employed in the manufacture of gun-powder. When very subtile or valuable materials are to be sifted, which are easily dispersed, or when the finer parts of the powder may be hurtful, a compound sieve, Fig. 15. is made use of, which consists of the sieve ABCD,

with a lid EF, and receiver GH; these three parts are represented as joined together for use, Fig. 14.

There is a method of procuring powders of an uniform fineness, considerably more accurate than the sieve; but it can only be used with such substances as are not acted upon by water. The powdered substance is mixed and agitated with water, or any other convenient fluid. The liquor is allowed to settle for a few moments, and is then decanted off. The coarser powder remains at the bottom of the vessel, and the finer passes over with the liquid. By repeated decantations in this manner, various sediments are obtained, of different degrees of fineness; the last sediment, or that which remains longest suspended in the liquor, being the finest. This process may likewise be used with advantage for separating substances of different degrees of specific gravity, though of the same fineness. This last is chiefly employed in mining, for separating the heavier metallic ores from the lighter earthy matters with which they are mixed.

In chemical laboratories, pans and jugs of glass or earthen-ware, are employed for this operation. Sometimes, for decanting the liquor without disturbing the sediment, the glass syphon ABCH, Pl. II. Fig. 11. is used, which may be supported by means of the perforated board DE, at the

proper depth in the vessel FG, to draw off all the liquor required into the receiver LM. The principles and application of this useful instrument are so well known, as to need no explanation.

### SECT. III.

#### *Of Filtration.*

A filtre is a species of very fine sieve, which is permeable to the particles of fluids, but through which the particles of the finest powdered solids are incapable of passing; hence its use in separating fine powders from suspension in fluids. In pharmacy, very close and fine woollen cloths are chiefly used for this operation. These are commonly formed in a conical shape, Pl. II. Fig. 2. which has the advantage of uniting all the liquor which drains through, into a point A, where it may be readily collected in a narrow mouthed vessel. In large pharmaceutical laboratories, this filtering bag is stretched upon a wooden-stand, Pl. II. Fig. 1.

For the purposes of chemistry, as it is requisite to have the filters perfectly clean, unsized paper is substituted instead of cloth or flannel;

through this substance, no solid body, however finely it be powdered, can penetrate, and fluids percolate through it with the greatest readiness. As paper breaks easily when wet, various methods of supporting it are used, according to circumstances. When a large quantity of fluid is to be filtrated, the paper is supported by the frame of wood, Pl. II. Fig. 3. ABCD, having a piece of coarse cloth stretched over it, by means of iron-hooks. This cloth must be well cleaned each time it is used; or even new cloth must be employed, if there be reason to suspect its being impregnated with any thing which can injure the subsequent operations. In ordinary operations, where moderate quantities of fluid are to be filtrated, different kinds of glass funnels are used for supporting the paper, as represented Pl. II Fig. 5. 6. and 7. When several filtrations must be carried on at once, the board or shelf AB, Fig. 9. supported upon stands C and D, and pierced with round holes, is very convenient for containing the funnels.

Some liquors are so thick and clammy, as not to be able to penetrate through paper without some previous preparation, such as clarification by means of white of eggs, which, being mixed with the liquor, coagulates when brought to boil; and, entangling the greater part of the impurities of the liquor, rises with them to the



surface in the state of scum. Spiritous liquors may be clarified in the same manner by means of isinglass dissolved in water, which coagulates by the action of the alkohol without the assistance of heat.

As most of the acids are produced by distillation, and are consequently clear, we have rarely any occasion to filtrate them. But if, at any time, concentrated acids require this operation, it is impossible to employ paper, which would be corroded and destroyed by the acid. For this purpose, pounded glass, or rather quartz or rock-crystal, broken in pieces, and grossly powdered, answers very well. A few of the larger pieces are put in the neck of the funnel: these are covered with the smaller pieces; the finer powder is placed over all: and the acid is poured on at top. For the ordinary purposes of society, river-water is frequently filtrated by means of clean washed sand, to separate its impurities, or by means of certain porous stones, called filtering stones, cut into a convenient form.

#### SECT. IV.

##### *Of Decantation.*

This operation is often substituted, instead of filtration for separating solid particles which are

diffused through liquors. These are allowed to settle in conical vessels, ABCDE, Pl. II. Fig. 10. the diffused matters gradually subside, and the clear fluid is gently poured off. If the sediment be extremely light, and apt to mix again with the fluid by the slightest motion, the syphon, Fig. 11. is used, instead of decantation, for drawing off the clear fluid.

In experiments, where the weight of the precipitate must be rigorously ascertained, decantation is preferable to filtration, providing the precipitate be several times washed in a considerable proportion of water. The weight of the precipitate may indeed be ascertained, by carefully weighing the filtre before and after the operation. But, when the quantity of precipitate is small, the different proportions of moisture retained by the paper, in a greater or lesser degree of exsiccation, may prove a material source of error, which ought carefully to be guarded against.

## C H A P V.

*Of Chemical Means for separating the Particles of Bodies from each other, without Decomposition, and for uniting them again.*

I Have already shewn, that there are two methods of dividing the particles of bodies, the *mechanical* and *chemical*. The former only separates a solid mass into a great number of smaller masses; and for these purposes various species of forces are employed, according to circumstances, such as the strength of man or of animals, the weight of water applied through the means of hydraulic engines, the expansive power of steam, the force of the wind, &c. By all or any of these mechanical powers, however, we can never reduce substances into powder beyond a certain degree of fineness: and the smallest particle produced in this way, though it seems very minute to our organs, is still in fact a mountain, when compared with the ultimate elementary particles of the pulverized substance.

The chemical agents, on the contrary, divide bodies into their primitive particles. If, for instance, a neutral salt be acted upon by these, it is divided, as far as is possible, without ceasing

to be a neutral salt. In this Chapter, I mean to give examples of this kind of division of bodies, to which I shall add some account of the relative operations.

## S E C T. I.

*Of the Solution of Salts.*

In chemical language, the terms of *solution* and *dissolution* have long been confounded; and have very improperly been indiscriminately employed for expressing both the division of the particles of a salt in a fluid, such, as water, and the division of a metal in an acid. A few reflections upon the effects of these two operations will suffice to show that they ought not to be confounded together. In the solution of salts, the saline particles are only separated from each other, while neither the salt nor the water are at all decomposed; for we are able to recover both the one and the other in the same quantity as before the operation. The same thing takes place in the solution of resins in alkohol. During metallic dissolutions, on the contrary, a decomposition, either of the acid, or of the water which dilutes it, always takes place. The metal combines with oxygen; and is changed

into an oxyd ; and a gasseous substance is disengaged ; so that in reality none of the substances employed remain, after the operation, in the same state they were in before. This article is entirely confined to the consideration of solution.

To understand properly what takes place during the solution of salts, it is necessary to know, that, in most of these operations, two distinct effects are complicated together, viz. solution by water, and solution by caloric : and, as the explanation of most of the phenomena of solution depends upon the distinction of these two circumstances, I shall enlarge a little upon their nature.

Nitrat of potash, usually called nitre or salt-petre, contains very little water of crystallization, perhaps even none at all. Yet this salt liquifies in a degree of heat very little superior to that of boiling water. This liquefaction cannot therefore be produced by means of the water of crystallization, but in consequence of the salt being very fusible in its nature, and from its passing from the solid to the liquid state of aggregation, when but a little raised above the temperature of boiling water. All salts are in this manner susceptible of being liquefied by caloric, but in higher or lower degrees of temperature. Some of these, as the acetites of potash and soda, liquefy with a very moderate heat ; while others,

as fulphat of potash, or of lime, &c. require the strongest fires we are capable of producing. This liquefaction of salts by caloric produces exactly the same phenomena with the melting of ice. It is accomplished in each salt by a determinate degree of heat, which remains invariably the same during the whole time of the liquefaction. Caloric is employed, and becomes fixed during the melting of the salt; and is, on the contrary, disengaged when the salt coagulates. These are general phenomena, which universally occur during the passage of every species of substance from the solid to the fluid state of aggregation, and from fluid to solid.

These phenomena, arising from solution by caloric, are always less or more conjoined with those which take place during solutions in water. We cannot pour water upon a salt, on purpose to dissolve it, without employing a compound solvent, both water and caloric. Hence we may distinguish several different cases of solution, according to the nature and mode of existence of each salt. If, for instance, a salt be difficultly soluble in water, and readily so by caloric, it evidently follows, that this salt will be scantily soluble in cold water, and considerably in hot water; such is nitrat of potash, and more especially oxygenated muriat of potash. If another salt be little soluble both in water and caloric, the difference of its solubility in cold and warm



water will be very inconsiderable : sulphat of lime is of this kind. From these considerations, it follows, that there is a necessary relation between the following circumstances ; the solubility of a salt in cold water, its solubility in boiling water, and the degree of temperature at which the same salt liquefies by caloric, unassisted by water ; and that the difference of solubility in hot and cold water is so much greater in proportion to its ready solution in caloric, or in proportion to its susceptibility of liquefying in a low degree of temperature.

The above is a general view of solution ; but, for want of particular facts, and sufficiently exact experiments, it is still nothing more than an approximation towards a particular theory. The means of completing this part of chemical science is extremely simple. We have only to ascertain how much of each salt is dissolved by a certain quantity of water at different degrees of temperature : and as, by the experiments published by Mr de la Place and me, the quantity of caloric contained in a pound of water at each degree of the thermometer is accurately known, it will be very easy to determine, by simple experiments, the proportion of water and caloric required for solution by each salt, what quantity of caloric is absorbed by each at the moment of liquefaction, and how much is disengaged at the moment of crystallization. Hence the reason

why salts are more rapidly soluble in hot than in cold water, is perfectly evident. In all solutions of salts, caloric is employed. When that is furnished intermediately from the surrounding bodies, it can only arrive slowly to the salt; whereas this is greatly accelerated, when the requisite caloric exists, ready combined with the water of solution.

In general the specific gravity of water is augmented by holding salts in solution; but there are some exceptions to the rule. Some time hence, the quantities of radical, of oxygen, and of base, which constitute each neutral salt, the quantity of water and caloric necessary for solution, the increased specific gravity communicated to water, and the figure of the elementary particles of the crystals, will all be accurately known. From these all the circumstances and phenomena of chrySTALLIZATION will be explained: and by these means this part of chemistry will be completed. Mr Seguin has formed the plan of a thorough investigation of this kind, which he is extremely capable of executing.

The solution of salts in water requires no particular apparatus; small glass phials of different sizes, Pl. II. Fig. 16. and 17. pans of earthenware, A, Fig. 1. and 2. long-necked matrasses, Fig. 14. and pans or basons of copper or of silver, Fig. 13. and 15. answer very well for these operations.

## S E C T. II.

*Of Lixiviation.*

This is an operation used in chemistry and manufactures for separating substances which are soluble in water, from such as are insoluble. The large vat or tub, Pl. 2. Fig. 12. having a hole D near its bottom, containing a wooden-spigot and foffet, or metallic stop-cock DE, is generally used for this purpose. A thin stratum of straw is placed at the bottom of the tub : over this, the substance to be lixiviated is laid, and covered by a cloth : then hot or cold water, according to the degree of solubility of the saline matter, is poured on. When the water is supposed to have dissolved all the saline parts, it is let off by the stop-cock : and, as some of the water charged with salt necessarily adheres to the straw and insoluble matters, several fresh quantities of water are poured on. The straw serves to secure a proper passage for the water, and may be compared to the straws or glass rods used in filtering, to keep the paper from touching the sides of the funnel. The cloth, which is laid over the matters under lixiviation, prevents the water from

making a hollow in these substances where it is poured on, through which it might escape without acting upon the whole mass.

This operation is less or more imitated in chemical experiments; but as in these, especially with analytical views, greater exactness is required, particular precautions must be employed, so as not to leave any saline or soluble part in the residuum. More water must be employed than in ordinary lixiviations; and the substances ought to be previously stirred up in the water, before the clear liquor is drawn off, otherwise the whole mass might not be equally lixiviated; and some parts might even escape altogether from the action of the water. We must likewise employ fresh portions of water in considerable quantity, until it comes off entirely free from salt, which we may ascertain by means of the hydrometer formerly described.

In experiments with small quantities, this operation is conveniently performed in jugs or matraffes of glass, and by filtrating the liquor through paper in a glass funnel. When the substance is in larger quantity, it may be lixiviated in a kettle of boiling-water, and filtrated through paper, supported by cloth, in the wooden frame, Pl. II. Fig. 3. and 4: and in operations in the large way, the tub already mentioned must be used.

## S E C T. III.

*Of Evaporation.*

This operation is used for separating two substances from each other, of which one at least must be fluid, and whose degrees of volatility are considerably different. By this means we obtain a salt, which has been dissolved in water, in its concrete form. The water, by heating, becomes combined with caloric, which renders it volatile; while the particles of the salt being brought nearer to each other, and within the sphere of their mutual attraction, unite into the solid state.

As it was long thought that the air had great influence upon the quantity of fluid evaporated, it will be proper to point out the errors which this opinion has produced. There certainly is a constant flow evaporation from fluids exposed to the free air: and, though this species of evaporation may be considered in some degree as a solution in air, yet caloric has considerable influence in producing it; as is evident from the refrigeration which always accompanies this process; hence we may consider this gradual evaporation as a compound solution, made partly in

air, and partly in caloric. But the evaporation which takes place from a fluid kept continually boiling, is quite different in its nature: and in it the evaporation produced by the action of the air is exceedingly inconsiderable in comparison with that which is occasioned by caloric. This latter species may be termed *vaporization* rather than *evaporation*. This process is not accelerated in proportion to the extent of evaporating surface, but in proportion to the quantities of caloric which combine with the fluid. Too free a current of cold air is often hurtful to this process; as it tends to carry off caloric from the water, and consequently retards its conversion into vapour. Hence there is no inconvenience produced by covering, in a certain degree, the vessels in which liquids are evaporated by continual boiling, provided the covering body be of such a nature as does not strongly draw off the caloric, or, to use an expression of Dr Franklin's, provided it be a bad conductor of heat. In this case, the vapours escape through such opening as is left; and at least as much is evaporated, frequently more than when free access is allowed to the external air.

As, during evaporation, the fluid carried off by caloric is entirely lost, being sacrificed for the sake of the fixed substances with which it was combined, this process is only employed, where the fluid is of small value, as water, for instance.



But, when the fluid is of more consequence, we have recourse to distillation, in which process we preserve both the fixed substance and the volatile fluid. The vessels employed for evaporation, are basons or pans of copper, silver or lead, Pl. II. Fig. 13. and 15. or capsules of glass, porcelain, or stone water, Pl. II. A, Fig. 1. and 2. Pl. III. Fig. 3. and 4. The best utensils for this purpose are made of the bottoms of glass retorts and matrasses; as their equal thinness renders them more fit than any other kind of glass vessel for bearing a brisk fire, and sudden alterations of heat and cold, without breaking.

As the method of cutting these glass vessels is no where described in books, I shall here give a description of it, that they may be made by chemists for themselves out of spoiled retorts, matrasses, and recipients, at a much cheaper rate than any which can be procured from glass manufacturers. The instrument, Pl. III. Fig. 5. consisting of an iron ring AC, fixed to the rod AB, having a wooden handle D, is employed as follows: Make the ring red hot in the fire, and put it upon the matrafs G, Fig. 6. which is to be cut. When the glass is sufficiently heated, throw on a little cold water; and it will generally break exactly at the circular line heated by the ring.

Small flasks or phials of thin glass are exceeding good vessels for evaporating small quantities of fluid. They are very cheap, and stand the fire

remarkably. One or more of these may be placed upon a second grate above the furnace, Pl. III. Fig. 2. where they will only experience a gentle heat. By this means, a great number of experiments may be carried on at one time. A glass retort, placed in a sand-bath, and covered with a dome of baked earth, Pl. III. Fig. 1. answers pretty well for evaporations. But in this way, it is always considerably slower, and is even liable to accidents. As the sand heats unequally, and the glass cannot dilate in the same unequal manner, the retort is very liable to break. Sometimes the sand serves exactly the office of the iron ring formerly mentioned; for, if a single drop of vapour, condensed into liquid, happens to fall upon the heated part of the vessel, it breaks circularly at that place. When a very intense fire is necessary, earthen crucibles may be used—but we generally use the word *evaporation*, to express what is produced by the temperature of boiling water, or not much higher.

## S E C T. IV.

*Of Crystallization.*

In this process, the integrant parts of a solid body, separated from each other by the intervention of a fluid, are made to exert the mutual attraction of aggregation, so as to coalesce and reproduce a solid mass. When the particles of a body are only separated by caloric, and the substance is thereby retained in the liquid state, all that is necessary for making it crystallize, is to remove a part of the caloric which is lodged between its particles, or, in other words, to cool it. If this refrigeration be slow, and the body be at the same time left at rest, its particles assume a regular arrangement; and crystallization, properly so called, takes place. But, if the refrigeration be made rapidly, or if the liquor be agitated at the moment of its passage to the concrete state, the crystallization is irregular and confused.

The same phenomena occur with watery solutions, or rather in those made partly in water, and partly by caloric. So long as there remains a sufficiency of water and caloric to keep the particles of the body asunder beyond the sphere

of their mutual attraction, the salt remains in the fluid state. But, whenever either caloric or water is not present in sufficient quantity, and the attraction of the particles for each other becomes superior to the power which keeps them asunder, the salt recovers its concrete form; and the crystals produced are the more regular in proportion as the evaporation has been slower and more tranquilly performed.

All the phenomena we formerly mentioned as taking place during the solution of salts, occur in a contrary sense, during the crystallization. Caloric is disengaged at the instant of their assuming the solid state, which furnishes an additional proof of salt being held in solution by the compound action of water and caloric. Hence, to cause salts to crystallize, which readily liquefy by means of caloric, it is not sufficient to carry off the water which held them in solution, but the caloric united to them must likewise be removed. Nitrat of potash, oxygenated muriat of potash, alum, sulphat of soda, &c. are examples of this circumstance; as, to make these salts crystallize, refrigeration must be added to evaporation. Such salts, on the contrary, as require little caloric for being kept in solution, and which, from that circumstance, are almost equally soluble in cold and warm water, are crystallizable by simply carrying off the water which holds them in solution; and

M m m

even recover their solid state in boiling water ; such are sulphat of lime, muriat of potash and of soda, and several others.

The art of refining saltpetre depends upon these properties of salts, and upon their different degrees of solubility in hot and cold water. This salt, as produced in the manufactories by the first operation, is composed of many different salts. Some are deliquescent, and not susceptible of being crystalized, such as the nitrat and muriat of lime. Others are almost equally soluble in hot and cold water ; as the muriats of potash and of soda. And lastly, the saltpetre, or nitrat of potash, is greatly more soluble in hot than it is in cold water. The operation is begun by pouring upon this mixture of salts as much water as will hold even the least soluble, the muriats of soda and of potash, in solution. So long as it is hot, this quantity readily dissolves all the saltpetre : but upon cooling, the greater part of this salt crystalizes, leaving about a sixth part remaining dissolved, and mixed with the nitrat of lime and the two muriats. The nitre obtained by this process is still somewhat impregnated with other salts, because it has been crystallized from water in which these abound : It is completely purified from these by a second solution in a small quantity of boiling water and second crystallization. The water remaining after these crystallizations of nitre, is still loaded with a mix-

ture of saltpetre, and other salts. By farther evaporation, crude saltpetre, or rough-petre, as the workmen call it, is procured from it: and this is purified by two fresh solutions and crystallizations.

The deliquescent earthy salts, which do not contain the nitric acid, are rejected in this manufacture. But those which consist of that acid neutralized by an earthy base, are dissolved in water, the earth is precipitated by means of potash, and allowed to subside; the clear liquor is then decanted, evaporated, and allowed to crystallize. The above management for refining saltpetre, may serve as a general rule for separating salts from each other, which happen to be mixed together. The nature of each must be considered, the proportion in which each dissolves in given quantities of water, and the different solubility of each in hot and cold water. If to these we add the property which some salts possess, of being soluble in alcohol, or in a mixture of alcohol and water, we have many resources for separating salts from each other by means of crystallization; though it must be allowed, that it is extremely difficult to render this separation perfectly complete.

The vessels used for crystallization, are pans of earthen ware, A, Pl. II. Fig. 1. and 2. and large flat dishes, Pl. III. Fig. 7. When a saline solution is to be exposed to a slow evaporation



in the heat of the atmosphere, with free access of air, vessels of some depth, Pl. III. Fig. 3. must be employed, that there may be a considerable body of liquid. By this means, the crystals produced are of considerable size, and remarkably regular in their figure.

Every species of salt crystallizes in a peculiar form, and even each salt varies in the form of its crystals, according to circumstances, which take place during crystallization. We must not from thence conclude that the saline particles of each species are indeterminate in their figures: The primitive particles of all bodies, especially of salts, are perfectly constant in their specific forms. But the crystals which form in our experiments, are composed of congeries of minute particles, which, though perfectly equal in size and shape, may assume very dissimilar arrangements, and consequently produce a vast variety of regular forms, which have not the smallest apparent resemblance to each other, nor to the original crystal. This subject has been very ably treated by the Abbe Haüy, in several memoirs presented to the Academy, and in his work upon the structure of crystals. It is only necessary to extend generally to the class of salts the principles he has particularly applied to some crystallized stones.

## S E C T. V

*Of simple Distillation.*

As distillation has two distinct objects to accomplish, it is divisible into simple and compound : and, in this section, I mean to confine myself entirely to the former. When two bodies, of which one is more volatile than the other, or has more affinity to caloric, are submitted to distillation, our intention is to separate them from each other. The more volatile substance assumes the form of gas ; and is afterwards condensed by refrigeration in proper vessels. In this case, distillation, like evaporation, becomes a species of mechanical operation, which separates two substances from each other, without decomposing or altering the nature of either. In evaporation, our only object is to preserve the fixed body, without paying any regard to the volatile matter ; whereas, in distillation, our principal attention is generally paid to the volatile substance, unless when we intend to preserve both the one and the other. Hence, simple distillation is nothing more than evaporation produced in close vessels.

The most simple distilling vessel is a species

of bottle or matrafs, A, Pl. III. fig. 8. which has been bent from its original form BC to BD, and which is then called a retort. When used, it is placed either in a reverberatory furnace, Pl. XIII. fig. 2. or in a sand bath, under a dome of baked earth, Pl. III. Fig. 1. To receive and condense the products, we adapt a recipient, E. Pl. III. 9. which is luted to the retort.

Sometimes, more especially in pharmaceutical operations, the glass or stone ware cucurbit, A, with its capital B, Pl. III. Fig. 12. or the glass alembic and capital, Fig. 13. of one piece, is employed. This latter is managed by means of a tubulated opening T, fitted with a ground stopper of crystal. The capital, both of the cucurbit and alembic, has a furrow or trench, *r, r*, intended for conveying the condensed liquor into the beak RS, by which it runs out. As, in almost all distillations, expansive vapours are produced, which might burst the vessels employed, we are under the necessity of having a small hole, T, Fig. 9. in the balloon or recipient, through which these may find vent. Hence, in this way of distilling, all the products which are permanently æriform, are entirely lost: and even such as difficultly lose that state, have not sufficient space to condense in the balloon. This apparatus is not, therefore, proper for experiments of investigation; and can only be admitted in the ordinary operations of the laboratory or in

pharmacy. In the article appropriated for compound distillation, I shall explain the various methods which have been contrived for preserving the whole products from bodies in this process.

As glass or earthen vessels are very brittle, and do not readily bear sudden alterations of heat and cold, every well regulated laboratory ought to have one or more alembics of metal for distilling water, spiritous liquors, essential oils, &c. This apparatus consists of a cucurbit and capital of tinned copper or brass, Pl. III. Fig. 15. and 16. which, when judged proper, may be placed in the water bath, D, Fig. 17. In distillations, especially of spiritous liquors, the capital must be furnished with a refrigeratory, SS, Fig. 16. kept continually filled with cold water. When the water becomes heated, it is let off by the stop-cock, R, and renewed with a fresh supply of cold water. As the fluid distilled is converted into gas by means of caloric furnished by the fire of the furnace, it is evident, that it could not condense, and, consequently, that no distillation, properly speaking, could take place, unless it be made to deposit in the capital all the caloric it received in the cucurbit. With this view, the sides of the capital must always be preserved at a lower temperature than is necessary for keeping the distilling substance in the state of gas; and the water in

the refrigeratory is intended for this purpose. Water is converted into gas by the temperature of  $212^{\circ}$ ; alkohol by  $182.75^{\circ}$ ; and ether by  $104^{\circ}$ . Hence these substances cannot be distilled, or rather, they will fly off in the state of gas, unless the temperature of the refrigeratory be kept under these respective degrees.

In the distillation of spiritous and other expansive liquors, the above described refrigeratory is not sufficient for condensing all the vapours which arise. In this case, therefore, instead of receiving the distilled liquor immediately from the beak TU, of the capital into a recipient, a worm is interposed between them. This instrument is represented Pl. III. Fig. 18, contained in a worm tub of tinned copper. It consists of a metallic tube bent into a considerable number of spiral revolutions. The vessel, which contains the worm, is kept full of cold water, which is renewed as it grows warm. This contrivance is employed in all distilleries of spirits, without the intervention of a capital and refrigeratory, properly so called. The one represented in the plate is furnished with two worms, one of them being particularly appropriated to distillations of odoriferous substances.

In some simple distillations, it is necessary to interpose an adapter between the retort and receiver, as shewn Pl. III. Fig. 11. This may serve two different purposes; either to separate

two products of different degrees of volatility ; or to remove the receiver to a greater distance from the furnace, that it may be less heated. But these, and several other more complicated instruments of ancient contrivance, are far from producing the accuracy requisite in modern chemistry, as will be readily perceived, when I come to treat of compound distillation.

## S E C T. VI.

*Of Sublimation.*

This term is applied to the distillation of substances which condense in a concrete or solid form, such as the sublimation of sulphur, and of muriat of ammoniac, or sal ammoniac. These operations may be conveniently performed in the ordinary distilling vessels already described, though, in the sublimation of sulphur, a species of vessels, named alludels, have been usually employed. These are vessels of stone or porcelain ware, which adjust to each other over a cucurbit, containing the sulphur to be sublimed. One of the best subliming vessels, for substances which are not very volatile, is a flask, or phial of glass, sunk about two thirds into a



land bath; but in this way we are apt to lose a part of the products. When these are wished to be entirely preserved, we must have recourse to the pneumato-chemical distilling apparatus, to be described in the following chapter.

## CHAP. VI.

*Of Pneumato-chemical Distillations, Metallic Dissolutions, and some other Operations which require very Complicated Instruments..*

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## S E C T. I.

*Of Compound and Pneumato-chemical Distillations.*

**I**N the preceding chapter, I have only treated of distillation as a simple operation, by which two substances, differing in their degrees of volatility, may be separated from each other; but distillation often actually decomposes the substances submitted to its action, and becomes one of the most complicated operations in chemistry. In every distillation, the substance distilled must be brought to the state of gas, in the cucurbit or retort, by combination with caloric: In simple distillation, this caloric is given out in the refrigeratory or in the worm, and the substance again recovers its liquid or solid form; but the substances submitted to compound distillation

are absolutely decomposed ; one part, as for instance, the carbon they contain, remains fixed in the retort, and all the rest of the elements are reduced to gasses of different kinds. Some of these gasses are susceptible of being condensed, and of recovering their solid or liquid forms, while others are permanently æriform ; one part of these are absorbable by water, some by the alkalies, and others are not susceptible of being absorbed at all. An ordinary distilling apparatus, such as has been described in the preceding chapter, is quite insufficient for retaining or for separating these diversified products, and we are obliged to have recourse, for this purpose, to methods of a more complicated nature.

The apparatus I am about to describe is calculated for the most complicated distillations, and may be simplified or extended according to circumstances. It consists of a tubulated glass retort A, Pl. IV. Fig. 1. having its beak fitted to a tubulated balloon or recipient BC ; to the upper orifice D of the balloon a bent tube DE *fg* is adjusted, which, at its other extremity *g*, is plunged into the liquor contained in the bottle L, with three necks *xxx*. Three other similar bottles are connected with this first one, by means of three similar bent tubes disposed in the same manner ; and the farthest neck of the last bottle is connected with a jar in a pneumatio-chemical apparatus, by means of a bent

tube \*. A determinate weight of distilled water is usually put into the first bottle, and the other three have each a solution of caustic potash in water. The weight of all these bottles, and of the water and alkaline solution they contain, must be accurately ascertained. Every thing being thus disposed, the junctures between the retort and recipient, and of the tube D of the latter, must be luted with fat lute, covered over with slips of linen, spread with lime and white of egg; all the other junctures are to be secured by a lute made of wax and rosin melted together.

When all these dispositions are completed, and when, by means of heat applied to the retort A, the substance it contains becomes decomposed, it is evident that the least volatile products must condense or sublime in the beak or neck of the retort itself, where most of the concrete substances will fix themselves. The more volatile substances, as the lighter oils, ammoniac, and several others, will condense in the recipient GC, whilst the gasses, which are not susceptible of condensation by cold, will pass on by the tubes, and boil up through the liquors in the several bottles. Such as are absorbable

\* The representation of this apparatus, Pl. IV. Fig. 1. will convey a much better idea of its disposition than can possibly be given by the most laboured description.—T.

by water will remain in the first bottle, and those which caustic alkali can absorb will remain in the others ; while such gasses as are not susceptible of absorption, either by water or alkalies, will escape by the tube RM, at the end of which they may be received into jars in a pneumato-chemical apparatus. The carbon and fixed earth, &c. which form the substance or residuum, anciently called *caput mortuum*, remain behind in the retort.

In this manner of operating, we have always a very material proof of the accuracy of the analysis, as the whole weights of the products taken together, after the process is finished, must be exactly equal to the weight of the original substance submitted to distillation. Hence, for instance, if we have operated upon eight ounces of starch or gum arabic, the weight of the charry residuum in the retort, together with that of all the products gathered in its neck and the balloon, and of all the gas received into the jars by the tube RM added to the additional weight acquired by the bottles, must, when taken together, be exactly eight ounces. If the product be less or more, it proceeds from error, and the experiment must be repeated until a satisfactory result be procured, which ought not to differ more than six or eight grains in the pound from the weight of the substance submitted to experiment.

In experiments of this kind, I for a long time met with an almost insurmountable difficulty, which must at last have obliged me to desist altogether, but for a very simple method of avoiding it, pointed out to me by Mr Hassenfratz. The smallest diminution in the heat of the furnace, and many other circumstances inseparable from this kind of experiments, cause frequent reabsorptions of gas; when this occurs, the water in the cistern of the pneumato-chemical apparatus rushes into the last bottle through the tube RM; the same circumstance happens from one bottle into another, and the fluid is often forced even into the recipient C. This accident is prevented by using bottles having three necks, as represented in the plate, into one of which, in each bottle, a capillary glass-tube *St, st, st, st*, is adapted, so as to have its lower extremity *t* immersed in the liquor. If any absorption takes place, either in the retort, or in any of the bottles, a sufficient quantity of external air enters, by means of these tubes, to fill up the void; and we get rid of the inconvenience at the price of having a small portion of common air mixed with the products of the experiment, which is thereby prevented from failing altogether. Tho' these tubes admit the external air, they cannot permit any of the gaseous substances to escape, as they are always shut below by the water of the bottles.



It is evident, that, in the course of experiments with this apparatus, the liquor of the bottles must rise in these tubes in proportion to the pressure sustained by the gas or air contained in the bottles; and this pressure is determined by the height and gravity of the column of fluid contained in all the subsequent bottles. If we suppose that each bottle contains three inches of fluid, and that there are three inches of water in the cistern of the connected apparatus above the orifice of the tube RM, and allowing the gravity of the fluids to be only equal to that of water, it follows that the air in the first bottle must sustain a pressure equal to twelve inches of water; the water must therefore rise twelve inches in the tube S, connected with the first bottle, nine inches in that belonging to the second, six inches in the third, and three in the last; wherefore these tubes must be made somewhat more than twelve, nine, six, and three inches long respectively, allowance being made for oscillatory motions, which often take place in the liquids. It is sometimes necessary to introduce a similar tube between the retort and recipient; and as the tube is not immersed in fluid at its lower extremity, until some has collected in the progress of the distillation, its upper end must be shut at first with a little lute, so as to be opened according to necessity, or after

there is sufficient liquid in the recipient to secure its lower extremity.

This apparatus cannot be used in very accurate experiments, when the substances intended to be operated upon have a very rapid action upon each other, or when one of them can only be introduced in small successive portions, as in such as produce violent effervescence when mixed together. In such cases we employ a tubulated retort A, Pl. VII. Fig. 1. into which one of the substances is introduced, preferring always the solid body, if any such is to be treated. We then lute to the opening of the retort a bent tube BCDA, terminating at its upper extremity B in a funnel, and at its other end A in a capillary opening. The fluid material of the experiment is poured into the retort by means of this funnel, which must be made of such a length, from B to C, that the column of liquid introduced may counterbalance the resistance produced by the liquors contained in all the bottles, Pl. IV. Fig. 1.

Those, who have not been accustomed to use the above described distilling apparatus, may perhaps be startled at the great number of openings which require luting, and the time necessary for making all the previous preparations in experiments of this kind. It is very true, that, if we take into account all the necessary weighings of materials and products, both before and

after the experiments, these preparatory and succeeding steps require much more time and attention than the experiment itself. But, when the experiment succeeds properly, we are well rewarded for all the time and trouble bestowed, as, by one process carried on in this accurate manner, much more just and extensive knowledge is acquired, of the nature of the vegetable or animal substance thus submitted to investigation, than by many weeks assiduous labour in the ordinary method of proceeding.

When in want of bottles with three orifices, those with two may be used. It is even possible to introduce all the three tubes at one opening, so as to employ ordinary wide-mouthed bottles, provided the opening be sufficiently large. In this case we must carefully fit the bottles with corks very accurately cut, and boiled in a mixture of oil, wax, and turpentine. These corks are pierced with the necessary holes for receiving the tubes, by means of a round file, as in Pl. IV. Fig. 8.

## S E C T. II.

*Of Metallic Dissolutions.*

I have already pointed out the difference between solution of salts in water and metallic dissolutions. The former requires no particular vessels; whereas the latter require very complicated vessels of late invention, that we may not lose any of the products of the experiment, and may therefore procure truly conclusive results of the phenomena which occur. The metals, in general, dissolve in acids with effervescence, which is only a motion excited in the solvent by the disengagement of a great number of bubbles of air or aëriform fluid, which proceed from the surface of the metal, and break at the surface of the liquid.

Mr Cavendish and Dr Priestley were the first inventors of a proper apparatus for collecting these elastic fluids. That of Dr Priestley is extremely simple, and consists of a bottle A, Pl. VII. Fig. 2. with its cork B, through which passes the bent glass tube BC, which is engaged under a jar filled with water in the pneumatochemical apparatus, or simply in a basin full of water. The metal is first introduced into the

bottle ; the acid is then poured over it ; and the bottle is instantly closed with its cork and tube, as represented in the plate. But this apparatus has its inconveniences. When the acid is much concentrated, or the metal much divided, the effervescence begins before we have time to cork the bottle properly ; and some gas escapes, by which we are prevented from ascertaining the quantity disengaged with rigorous exactness. In the next place, when we are obliged to employ heat, or when heat is produced by the process, a part of the acid distils, and mixes with the water of the pneumato-chemical apparatus, by which means we are deceived in our calculation of the quantity of acid decomposed. Besides these, the water in the cistern of the apparatus absorbs all the gas produced, which is susceptible of absorption, and renders it impossible to collect these without loss.

To remedy these inconveniences, I at first used a bottle with two necks, Pl. VII. Fig. 3. into one of which the glass funnel BC is luted so as to prevent any air escaping. A glass rod DE is fitted with emery to the funnel, so as to serve the purpose of a stopper. When it is used, the matter to be dissolved is first introduced into the bottle ; and the acid is then permitted to pass in as slowly as we please, by raising the glass rod gently as often as is necessary until saturation is produced.

Another method has been since employed, which serves the same purpose, and is preferable to the last described in some instances. This consists in adapting to one of the mouths of the bottle A, Pl. VII. Fig. 4. a bent tube DEFG, having a capillary opening at D, and ending in a funnel at G. This tube is securely luted to the mouth C of the bottle. When any liquid is poured into the funnel, it falls down to F; and, if a sufficient quantity be added, it passes by the curvature E, and falls slowly into the bottle, so long as fresh liquor is supplied at the funnel. The liquor can never be forced out of the tube, and no gas can escape through it, because the weight of the liquid serves the purpose of an accurate cork.

To prevent any distillation of acid, especially in dissolutions accompanied with heat, this tube is adapted to the retort A, Pl. VII. Fig. 1. and a small tubulated recipient, M, is applied, in which any liquor which may distil is condensed. On purpose to separate any gas that is absorbable by water, we add the double-necked bottle L, half filled with a solution of caustic potash; the alkali absorbs any carbonic acid gas, and usually only one or two other gasses pass into the jar of the connected pneumato-chemical apparatus through the tube NO. In the first chapter of this third part, we have directed how these are to be separated and examined.



If one bottle of alkaline solution be not thought sufficient, two, three, or more, may be added.

### S E C T. III.

#### *Apparatus necessary in Experiments upon Vinous and Putrefactive Fermentations.*

For these operations a peculiar apparatus, especially intended for this kind of experiment, is requisite. The one I am about to describe, is finally adopted, as the best calculated for the purpose, after numerous corrections and improvements. It consists of a large matrafs A, Pl. X. Fig. 1. holding about twelve pints, with a cap of brass, *a*, *b*, strongly cemented to its mouth, and into which is screwed a bent tube *c d*, furnished with a stop-cock *e*. To this tube is joined the glass recipient B, having three openings, one of which communicates with the bottle C, placed below it. To the posterior opening of this recipient is fitted a glass tube *g h i*, cemented at *g* and *i* to collets of brass, and intended to contain a very deliquescent concrete neutral salt, such as nitrat or muriat of lime, acetite of potash, &c. This tube communicates with two bottles D and E, filled to *x* and *y* with a solution of caustic potash.

All the parts of this machine are joined together by accurate screws: and the touching parts have greased leather interposed, to prevent any passage of air. Each piece is likewise furnished with two stop-cocks, by which its two extremities may be closed; so that we can weigh each separately at any period of the operation.

The fermentable matter, such as sugar, with a proper quantity of yeast, and diluted with water, is put into the matrafs. Sometimes, when the fermentation is too rapid, a considerable quantity of froth is produced, which not only fills the neck of the matrafs, but passes into the recipient, and from thence runs down into the bottle C. On purpose to collect this scum and must, and to prevent it from reaching the tube filled with deliquescent salts, the recipient and connected bottle are made of considerable capacity.

In the vinous fermentation, only carbonic acid gas is disengaged, carrying with it a small proportion of water in solution. A great part of this water is deposited in passing through the tube *g b i*, which is filled with a deliquescent salt in gross powder: and the quantity is ascertained by the augmentation of the weight of the salt. The carbonic acid gas bubbles up through the alkaline solution in the bottle D, to which it is conveyed by the tube *k l m*. Any small portion which may not be absorbed by this

first bottle, is secured by the solution in the second bottle E; so that nothing, in general, passes into the jar F, except the common air contained in the vessels at the commencement of the experiment.

The same apparatus answers extremely well for experiments upon the putrefactive fermentation: but, in this case a considerable quantity of hydrogen gas is disengaged through the tube *q r s t u*, by which it is conveyed into the jar F; and, as this disengagement is very rapid, especially in summer, the jar must be frequently changed. These putrefactive fermentations require constant attendance from the above circumstance: whereas the vinous fermentation hardly needs any. By means of this apparatus, we can ascertain, with great precision, the weights of the substances submitted to fermentation, and of the liquid and aëriform products which are disengaged. What has been already said, in Part I. Chap. XIII. upon the products of the vinous fermentation, may be consulted.

## S E C T. IV.

*Apparatus for the Decomposition of Water.*

Having already given an account, in the first part of this work, of the experiments relative to the decomposition of water, I shall avoid any unnecessary repetitions, and only give a few summary observations upon the subject in this section. The principal substances which have the power of decomposing water, are iron and charcoal; for which purpose they require to be made red hot, otherwise the water is only reduced into vapour, and condenses afterwards by refrigeration, without sustaining the smallest alteration. In a red heat, on the contrary, iron or charcoal carry off the oxygen from its union with hydrogen; in the first case, black oxyd of iron is produced, and the hydrogen is disengaged pure in form of gas; in the other case, carbonic acid gas is formed, which disengages, mixed with the hydrogen gas, and this latter is commonly carbonated, or holds carbon in solution.

A musket-barrel, without its breach pin, answers exceedingly well for the decomposition of water, by means of iron, and one should be

chosen of considerable length, and pretty strong. When too short, so as to run the risk of heating the lute too much, a tube of copper must be strongly foldered to one end. The barrel is placed in a long furnace CDEF, Pl. VII. Fig. 11. so as to have a few degrees of inclination from E to F; a glass retort A, is luted to the upper extremity E, which contains water, and is placed upon the furnace VVXX. The lower extremity F is luted to a worm SS, which is connected with the tubulated bottle H, in which any water distilled without decomposition, during the operation, collects, and the disengaged gas is carried by the tube KK to jars in a pneumato-chemical apparatus. Instead of the retort, a funnel may be employed, having its lower part shut by a stop-cock, through which the water is allowed to drop gradually into the gun-barrel. Immediately upon getting into contact with the heated part of the iron, the water is converted into steam, and the experiment proceeds in the same manner as if it were furnished in vapours from the retort.

In the experiment made by Mr Meusnier and me before a committee of the Academy, we used every precaution to obtain the greatest possible precision in the result of our experiment, having even exhausted all the vessels employed before we began, so that the hydrogen gas obtained might be free from any mixture of azotic gas. The re-

sults of that experiment will hereafter be given at large in a particular memoir.

In numerous experiments we are obliged to use tubes of glass, porcelain or copper, instead of gun-barrels; but glass has the disadvantage of being easily melted and flattened, if the heat be in the smallest degree raised too high; and porcelain is mostly full of small minute pores, through which the gas escapes, especially when compressed by a column of water. For these reasons I procured a tube of brass, which Mr de la Briche got cast and bored out of the solid for me at Strasburg, under his own inspection. This tube is extremely convenient for decomposing alkohol, which resolves into carbon, carbonic acid gas, and hydrogen gas; it may likewise be used with the same advantage for decomposing water by means of charcoal, and in a great number of experiments of this nature.



## C H A P. VII.

*Of the Composition and Application of Lutes.*

THE necessity of properly securing the junctures of chemical vessels, to prevent the escape of any of the products of experiments, must be sufficiently apparent; for this purpose lutes are employed, which ought to be of such a nature as to be equally impenetrable to the most subtile substances, as glass itself, through which only caloric can escape.

This first object of lutes is very well accomplished by bees wax, melted with about an eighth part of turpentine. This lute is very easily managed, sticks very closely to glass, and is very difficultly penetrable; it may be rendered more consistent, and less or more hard or pliable, by adding different kinds of resinous matters. Tho' this species of lute answers extremely well for retaining gasses and vapours, there are many chemical experiments which produce considerable heat, by which this lute becomes liquefied, and consequently the expansive vapours must very readily force through and escape.

For such cases, the following fat lute is the best hitherto discovered, though not without its disadvantages, which shall be pointed out. Take very pure and dry unbaked clay, reduced to a fine powder ; put this into a brass mortar ; and beat it, for several hours, with a heavy iron pestle, dropping in slowly some boiled lintseed oil. This is oil which has been oxygenated, and has acquired a drying quality, by being boiled with litharge. This lute is more tenacious, and applies better, if amber varnish be used instead of the above oil. To make this varnish, melt some yellow amber in an iron ladle, by which operation it loses a part of its succinic acid, and essential oil ; and mix it with lintseed oil. Though the lute prepared with this varnish, is better than that made with boiled oil, yet, as its additional expence is hardly compensated by its superior quality, it is seldom used.

The above fat lute is capable of sustaining a very violent degree of heat ; is impenetrable by acids and spiritous liquors ; and adheres exceedingly well to metals, stone ware, or glass, provided they have been previously rendered perfectly dry. But if, unfortunately, any of the liquor in the course of an experiment gets thro', either between the glass and the lute, or between the layers of the lute itself, so as to moisten the part, it is extremely difficult to close

the opening. This is the chief inconvenience which attends the use of fat lute, and perhaps the only one it is subject to. As it is apt to soften by heat, we must surround all the junctures with slips of wet bladder, applied over the luting, and fixed on by pack-thread tied round both above and below the joint. The bladder, and consequently the lute below, must be farther secured by a number of turns of pack-thread all over it. By these precautions, we are free from every danger of accident ; and the junctures secured in this manner may be considered, in experiments, as hermetically sealed.

It frequently happens that the figure of the junctures prevents the application of ligatures, which is the case with the three-necked bottles formerly described : and it even requires great address to apply the twine without shaking the apparatus ; so that, where a number of junctures require luting, we are apt to displace several, while securing one. In these cases we may substitute slips of linen, spread with white of egg and lime mixed together, instead of the wet bladder. These are applied while still moist, and very speedily dry and acquire considerable hardness. Strong glue, dissolved in water, may answer instead of white of egg. These fillets are usefully applied likewise over junctures luted together with wax and rosin.

Before applying a lute, all the junctures of the vessels must be accurately and firmly fitted to each other, so as not to admit of being moved. If the beak of a retort is to be luted to the neck of a recipient, they ought to fit pretty accurately; otherwise we must fix them by introducing short pieces of soft wood, or of cork. If the disproportion between the two be very considerable, we must employ a cork which fits the neck of the recipient, having a circular hole of proper dimensions to admit the beak of the retort. The same precaution is necessary in adapting bent tubes to the necks of bottles in the apparatus, represented Pl. IV. Fig. 1. and others of a similar nature. Each mouth of each bottle must be fitted with a cork, having a hole made with a round file of a proper size for containing the tube. And, when one mouth is intended to admit two or more tubes, which frequently happens when we have not a sufficient number of bottles with two or three necks, we must use a cork with two or three holes, Pl. IV. Fig. 8.

When the whole apparatus is thus solidly joined, so that no part can play upon another, we begin to lute. The lute is softened by kneading and rolling it between the fingers, with the assistance of heat, if necessary. It is rolled into little cylindrical pieces, and applied to the junctures, taking great care to make it

apply close, and adhere firmly, in every part ; a second roll is applied over the first, so as to pass it on each side ; and so on till each juncture be sufficiently covered. After this, the slips of bladder, or of linen, as above directed, must be carefully applied over all. Though this operation may appear extremely simple, yet it requires peculiar delicacy and management. Great care must be taken not to disturb one juncture whilst luting another, and more especially when applying the fillets and ligatures.

Before beginning any experiment, the closeness of the luting ought always to be previously tried, either by slightly heating the retort A, Pl. IV. Fig. 1. or by blowing in a little air by some of the perpendicular tubes S s s s. The alteration of pressure causes a change in the level of the liquid in these tubes. If the apparatus be accurately luted, this alteration of level will be permanent ; whereas, if there be the smallest opening in any of the junctures, the liquid will very soon recover its former level. It must always be remembered, that the whole success of experiments in modern chemistry depends upon the exactness of this operation, which therefore requires the utmost patience, and most attentive accuracy.

It would be of infinite service to enable chemists, especially those who are engaged in pneumatic processes, to dispense with the use of lutes,

or at least to diminish the number necessary in complicated instruments. I once thought of having my apparatus constructed so as to unite in all its parts by fitting with emery, in the way of bottles with crystal stoppers; but the execution of this plan was extremely difficult. I have since thought it preferable to substitute columns of a few lines of mercury in place of lutes; and have got an apparatus constructed upon this principle, which appears capable of very convenient application in a great number of circumstances.

It consists of a double-necked bottle A, Pl: XII. Fig. 12. The interior neck *b c* communicates with the inside of the bottle: and the exterior neck or rim *d e* leaves an interval between the two necks, forming a deep gutter intended to contain the mercury. The cap or lid of glass B enters this gutter, and is properly fitted to it, having notches in its lower edge for the passage of the tubes which convey the gas. These tubes, instead of entering directly into the bottles, as in the ordinary apparatus, have a double bend for making them enter the gutter, as represented in Fig. 13. and for making them fit the notches of the cap B. They rise again from the gutter to enter the inside of the bottle over the border of the inner mouth. When the tubes are disposed in their proper places, and the cap firmly fitted on, the gutter is filled with



mercury, by which means the bottle is completely excluded from any communication, excepting through the tubes. This apparatus may be very convenient in many operations in which the substances employed have no action upon mercury. Pl. XII. Fig. 14. represents an apparatus upon this principle properly fitted together.

Mr Seguin, to whose active and intelligent assistance I have been very frequently much indebted, has bespoken for me, at the glass-houses, some retorts hermetically united to their recipients, by which luting will be altogether unnecessary.

## C H A P. VIII.

*Of Operations upon Combustion and Deflagration.*

## S E C T. I.

*Of Combustion in General.*

COMBUSTION, according to what has been already said in the First Part of this Work, is the decomposition of oxygen gas produced by a combustible body. The oxygen which forms the base of this gas, is absorbed by, and enters into combination with, the burning body, while the caloric and light are set free. Every combustion, therefore, necessarily supposes oxygenation; whereas, on the contrary, every oxygenation does not necessarily imply concomitant combustion; because combustion, properly so called, cannot take place without disengagement of caloric and light. Before combustion can take place, it is necessary that the base of oxygen gas should have greater affi-

nity to the combustible body, than it has to caloric : and this elective attraction, to use Bergman's expression, can only take place at a certain degree of temperature, which is different for each combustible substance. Hence the necessity of giving a first motion or beginning to every combustion by the approach of a heated body. This necessity of heating any body we mean to burn, depends upon certain considerations, which have not hitherto been attended to by any natural philosopher; wherefore I shall enlarge a little upon the subject in this place.

Nature is at present in a state of equilibrium, which cannot have been attained until all the spontaneous combustions or oxygenations possible in the ordinary degrees of temperature had taken place. Hence, no new combustions or oxygenations can happen without destroying this equilibrium, and raising the combustible substances to a superior degree of temperature. To illustrate this abstract view of the matter by example: Let us suppose the usual temperature of the earth a little changed, and that it were raised only to the degree of boiling water. It is evident, that, in this case, phosphorus, which is combustible in a considerably lower degree of temperature, would no longer exist in nature in its pure and simple state, but would always be procured in its acid or oxygenated state ; and its radical would become one of the substances un-

known to chemistry. By gradually increasing the temperature of the earth, the same circumstance would successively happen to all the bodies capable of combustion; and, at last, every possible combustion having taken place, there would no longer exist any combustible body whatever; as every substance, susceptible of that operation, would be oxygenated, and consequently incombustible.

There cannot, therefore, exist, so far as relates to us, any combustible body, except such as are incombustible in the ordinary temperatures of the earth; or, what is the same thing, in other words, that it is essential to the nature of every combustible body, not to possess the property of combustion, unless heated, or raised to the degree of temperature at which its combustion naturally takes place. When this degree is once produced, combustion commences; and the caloric, which is disengaged by the decomposition of the oxygen gas, keeps up the temperature necessary for continuing combustion. When this is not the case, that is, when the disengaged caloric is insufficient for keeping up the necessary temperature, the combustion ceases. This circumstance is expressed in common language by saying, that a body burns ill, or with difficulty.

Although combustion possesses some circumstances in common with distillation, especially

with the compound kind of that operation, they differ in a very material point. In distillation, there is a separation of one part of the elements of the substance from each other, and a consequent combination of these, in a new order, occasioned by the affinities which take place in the increased temperature produced during distillation. This likewise happens in combustion, but with this farther circumstance, that a new element, not originally in the body, is brought into action: oxygen is added to the substance submitted to the operation, and caloric is disengaged.

The necessity of employing oxygen in the state of gas in all experiments with combustion, and the rigorous determination of the quantities employed, render this kind of operations peculiarly troublesome. As almost all the products of combustion are disengaged in the state of gas, it is still more difficult to retain them than even those furnished during compound distillation. Hence this precaution was entirely neglected by the ancient chemists; and this set of experiments exclusively belongs to modern chemistry.

Having thus pointed out, in a general way, the objects to be had in view in experiments upon combustion, I proceed, in the following sections of this chapter, to describe the different instruments I have used with this view. The following arrangement is formed, not upon the

nature of the combustible bodies, but upon that of the instruments necessary for combustion.

## S E C T. II.

### *Of the Combustion of Phosphorus.*

In these combustions, we begin by filling a jar, capable at least of holding six pints, with oxygen gas, in the water apparatus, Pl. V. Fig. 1. When it is perfectly full, so that the gas begins to flow out below, the jar A is carried to the mercury apparatus, Pl. IV. Fig. 3. We then dry the surface of the mercury, both within and without the jar, by means of blotting-paper, taking care to keep the paper for some time entirely immersed in the mercury before it is introduced under the jar, lest we let in any common air, which adheres very obstinately to the surface of the paper. The body to be submitted to combustion, being first very accurately weighed in nice scales, is placed in a small flat shallow dish, D, of iron or porcelain. This is covered by the larger cup P, which serves the office of a diving bell: and the whole is passed through the mercury into the jar; after which the larger cup is retired. The difficulty of passing the materials of combustion in this manner



through the mercury, may be avoided by raising one of the sides of the jar, A, for a moment, and slipping in the little cup, D, with the combustible body, as quickly as possible. In this manner of operating, a small quantity of common air gets into the jar: but it is so very inconsiderable as not to injure either the progress or accuracy of the experiment, in any sensible degree.

When the cup, D, is introduced under the jar, we suck out a part of the oxygen gas, so as to raise the mercury to EF, as formerly directed, Part I. Chap. V; otherwise, when the combustible body is set on fire, the gas becoming dilated, would be in part forced out, and we should no longer be able to make any accurate calculation of the quantities before and after the experiment. A very convenient mode of drawing out the air is by means of an air-pump syringe adapted to the syphon, GHI, by which the mercury may be raised to any degree under twenty-eight inches. Very inflammable bodies, as phosphorus, are set on fire by means of the crooked iron wire, MN, Pl. IV. Fig. 16. made red hot, and passed quickly through the mercury. Such as are less easily set on fire, have a small portion of tinder, upon which a minute particle of phosphorus is fixed, laid upon them before using the red hot iron.

In the first moment of combustion, the air, being heated, rarefies, and the mercury descends. But when, as in combustions of phosphorus and iron, no elastic fluid is formed, absorption becomes presently very sensible, and the mercury rises high into the jar. Great attention must be used, not to burn too large a quantity of any substance in a given quantity of gas; otherwise, towards the end of the experiment, the cup would approach so near the top of the jar, as to endanger breaking it, by the great heat produced, and the sudden refrigeration from the cold mercury. For the methods of measuring the volume of the gasses, and for correcting the measures according to the height of the barometer and thermometer, &c. see Chap. II. Sect. V. and VI. of this Part.

The above process answers very well for burning all the concrete substances, and even for the fixed oils. These last are burnt in lamps under the jar, and are readily set on fire by means of tinder, phosphorus, and hot iron. But it is dangerous for substances susceptible of evaporating in a moderate heat, such as ether, alkohol, and the essential oils. These substances dissolve in considerable quantity in oxygen gas: and, when set on fire, a dangerous and sudden explosion takes place, which forces up the jar to a great height, and dashes it in a thousand pieces. From the effects of two such explosions, some of the mem-

bers of the Academy and myself escaped very narrowly. Besides, though this manner of operating is sufficient for determining pretty accurately the quantity of oxygen gas absorbed, and of carbonic acid produced; yet as water is likewise formed in all experiments upon vegetable and animal matters, which contain an excess of hydrogen, this apparatus can neither collect it, nor determine its quantity. The experiment with phosphorus is even incomplete in this way; as it is impossible to demonstrate that the weight of the phosphoric acid produced, is equal to the sum of the weights of the phosphorus burnt and of oxygen gas absorbed during the process, I have been, therefore, obliged to vary the instruments according to circumstances, and to employ several of different kinds, which I shall describe in their order, beginning with that used for burning phosphorus.

Take a large balloon, A, Pl. IV. Fig. 4. of crystal or white glass, with an opening, EF, about two inches and a half, or three inches, diameter, to which a cap of brass is accurately fitted with emery, and which has two holes for the passage of the tubes *xxx*, *yyy*. Before shutting the balloon with its cover, place within it the stand, BC, supporting the cup of porcelain, D, which contains the phosphorus. Then lute on the cap with fat lute, allow it to dry for some days, and weigh the whole accurately.

After this exhaust the balloon by means of an air-pump, connected with the tube *xxx*, and fill it with oxygen gas by the tube *yyy*, from the gazometer, Pl. VIII. Fig. 1. described Chap. II. Sect. II. of this Part. The phosphorus is then set on fire by means of a burning-glass; and is allowed to burn till the cloud of concrete phosphoric acid stops the combustion, oxygen gas being continually supplied from the gazometer. When the apparatus has cooled, it is weighed and unluted. The tare of the instrument being allowed, the weight is that of the phosphoric acid contained. It is proper, for greater accuracy, to examine the air or gas contained in the balloon after combustion, as it may happen to be somewhat heavier or lighter than common air: and this difference of weight must be taken into account in the calculations upon the results of the experiment.

### S E C T. III.

#### *Of the Combustion of Charcoal.*

The apparatus I have employed for this process, consists of a small conical furnace of hammered copper, represented in perspective, Pl. XII. Fig. 9. and internally displayed Fig. 11. It is

divided into the furnace, ABC, where the charcoal is burnt, the grate, *de*, and the ash-hole, F. The tube, GH, in the middle of the dome of the furnace, serves to introduce the charcoal, and as a chimney for carrying off the air which has served for combustion. Through the tube, *lmn*, which communicates with the gazometer, the oxygen gas, or air, intended for supporting the combustion, is conveyed into the ash-hole, F, whence it is forced, by the application of pressure to the gazometer, to pass through the grate, *de*, and to blow upon the burning charcoal placed immediately above.

Oxygen gas, which forms  $\frac{2.8}{100}$  parts of atmospheric air, is changed into carbonic acid gas during combustion with charcoal, while the azotic gas of the air is not at all altered. Hence, after the combustion of charcoal in atmospheric air, a mixture of carbonic acid gas and azotic gas must remain. To allow this mixture to pass off, the tube, *op*, is adapted to the chimney, GH, by means of a screw at G, and conveys the gas into bottles half filled with solution of caustic potash. The carbonic acid gas is absorbed by the alkali : and the azotic gas is conveyed into a second gazometer, where its quantity is ascertained.

The weight of the furnace, ABC, is first accurately determined ; then the tube RS, of known weight, is introduced by the chimney, GH, till



its lower end *S*, rests upon the grate, *de*, which it occupies entirely. In the next place, the furnace is filled with charcoal; and the whole is weighed again, to know the exact quantity of charcoal submitted to experiment. The furnace is now put in its place; the tube, *lmn*, is screwed to that which communicates with the gazometer, and the tube, *op*, to that which communicates with the bottles of alkaline solution. Every thing being in readiness, the stop-cock of the gazometer is opened; a small piece of burning charcoal is thrown into the tube, *RS*, which is instantly withdrawn; and the tube, *op*, is screwed to the chimney, *GH*. The little piece of burning charcoal falls upon the grate; and in this manner gets below the whole charcoal; and is kept on fire by the stream of air from the gazometer. To be certain that the combustion is begun, and that it goes on properly, the tube *qrs*, is fixed to the furnace, having a piece of glass cemented to its upper extremity *s*, through which we can see if the charcoal be on fire.

I neglected to observe above, that the furnace, and its appendages, are plunged into water in the cistern, *TVXY*, Fig. 11. Pl. XII. to which ice may be added, to moderate the heat, if necessary; though the heat is by no means very considerable, as there is no air supplied but what comes from the gazometer, and no more of the charcoal



burns at one time, than what is immediately over the grate.

As one piece of charcoal is consumed, another falls down into its place, in consequence of the declivity of the sides of the furnace. This gets into the stream of air, from the grate, *d e*, and is burnt; and so on, successively, till the whole charcoal is consumed. The air, which has served the purpose of the combustion, passes through the mass of charcoal; and is forced, by the pressure of the gazometer, to escape through the tube, *o p*, and to pass through the bottles of alkaline solution.

This experiment furnishes all the necessary data for a complete analysis of atmospheric air and of charcoal. We know the weight of charcoal consumed. The gazometer gives us the measure of the air employed. The quantity and quality of gas remaining after combustion, may be determined, as it is received, either in another gazometer, or in jars, in a pneumato-chemical apparatus. The weight of ashes remaining in the ash-hole is readily ascertained: and, finally, the additional weight acquired by the bottles of alkaline solution gives the exact quantity of carbonic acid formed during the process. By this experiment, we may likewise determine, with sufficient accuracy, the proportions in which carbon and oxygen enter into the composition of carbonic acid.

In a future memoir, I shall give an account to the Academy, of a series of experiments I have undertaken, with this instrument, upon all the vegetable and animal charcoals. By some very slight alterations, this machine may be made to answer for observing the principal phenomena of respiration.

#### S E C T. IV.

##### *Of the Combustion of Oils.*

Oils are more compound in their nature than charcoal, being formed by the combination of at least two elements, carbon and hydrogen. Of course, after their combustion in common air, water, carbonic acid gas, and azotic gas remain. Hence the apparatus employed for their combustion requires to be adapted for collecting these three products, and is consequently more complicated than the charcoal furnace.

The apparatus I employ for this purpose, is composed of a large jar or pitcher A, Pl. XII. Fig. 4, surrounded at its upper edge by a rim of iron, properly cemented at DE, and receding from the jar at BC, so as to leave a furrow or gutter  $\kappa\kappa$ , between it and the outside of the jar,

somewhat more than two inches deep. The cover or lid of the jar, Fig. 5. is likewise surrounded by an iron rim  $fg$ , which adjusts into the gutter  $\pi\pi$ , Fig. 4. which being filled with mercury, has the effect of closing the jar hermetically in an instant, without using any lute: and as the gutter will hold about two inches of mercury, the air in the jar may be made to sustain the pressure of more than two feet of water, without danger of its escaping.

The lid has four holes,  $T\ h\ i\ k$ , for the passage of an equal number of tubes. The opening  $T$  is furnished with a leather box, through which passes the rod, Fig. 3. intended for raising and lowering the wick of the lamp, as will be afterwards directed. The three other holes are intended for the passage of three several tubes: one of these conveys the oil to the lamp; a second conveys air for keeping up the combustion; and the third carries off the air, after it has served for combustion. The lamp, in which the oil is burnt, is represented Fig. 2.;  $a$  is the reservoir of oil, having a funnel by which it is filled;  $b\ c\ d\ e\ f\ g\ h$  is a syphon which conveys the oil to the lamp  $11$ ;  $7, 8, 9, 10$ , is the tube which conveys the air for combustion from the gazometer to the same lamp. The tube  $bc$  is formed externally, at its lower end  $b$ , into a male screw, which turns in a female screw in the lid of the reservoir of oil  $a$ ; so that, by turning

the reservoir one way or the other, it is made to rise or fall, by which the oil is kept at the necessary level.

When the syphon is to be filled, and the communication formed between the reservoir of oil and the lamp, the stop-cock *c* is shut, and that at *e* opened. Oil is then poured in by the opening *f* at the top of the syphon, till it rises within three or four lines of the upper edge of the lamp; after which the stop-cock *k* is shut, and that at *c* opened. The oil is next poured in at *f*, till the branch *b c d* of the syphon is filled; and then the stop-cock *e* is closed. The two branches of the syphon being now completely filled, a communication is fully established between the reservoir and the lamp.

In Pl. XII. Fig. 1. all the parts of the lamp 11, Fig. 2. are represented magnified, to shew them distinctly. The tube *i k* carries the oil from the reservoir to the cavity *a a a a*, which contains the wick. The tube 9, 10, brings the air from the gazometer for keeping up the combustion. This air spreads through the cavity *d d d d*, and, by means of the passages *c c c c* and *b b b b*, is distributed on each side of the wick, after the principles of the lamps constructed by Argand, Quinquet, and Lange.

To render the whole of this complicated apparatus more easily understood, and that its description may make all others of the same kind

more readily followed, it is represented, completely connected together for use, in Pl. XI. The gazometer P furnishes air for the combustion, by the tube and stop-cock 1, 2. The tube 2, 3, communicates with a second gazometer, which is filled, while the first one is emptying during the process, that there may be no interruption to the combustion. 4, 5, is a tube of glass filled with deliquescent salts, for drying the air as much as possible in its passage: and the weight of this tube and its contained salts, at the beginning of the experiment, being known, it is easy to determine the quantity of water absorbed by them from the air. From this deliquescent tube, the air is conducted through the pipe 5, 6, 7, 8, 9, 10, to the lamp 11, where it spreads on both sides of the wick, as before described, and feeds the flame. One part of this air, which serves to keep up the combustion of the oil, forms carbonic acid gas and water, by oxygenating its elements. Part of this water condenses upon the sides of the pitcher A; and another part is held in solution in the air, by means of caloric furnished during the combustion. This air is forced, by the compression of the gazometer, to pass through the tube 12, 13, 14, 15, into the bottle 16, and the worm 17, 18, where the water is fully condensed from the refrigeration of the air: and, if any water still re-

main in solution, it is absorbed by deliquescent salts contained in the tube 19, 20.

All these precautions are solely intended for collecting and determining the quantity of water formed during the experiment. The carbonic acid and azotic gas remain to be ascertained. The former is absorbed by caustic alkaline solution in the bottles 22 and 25. I have only represented two of these in the figure; but nine at least are requisite: and the last of the series may be half filled with lime-water, which is the most certain reagent for indicating the presence of carbonic acid. If the lime-water be not rendered turbid, we may be certain that no sensible quantity of that acid remains in the air.

The rest of the air, which has served for combustion, and which chiefly consists of azotic gas, though still mixed with a considerable portion of oxygen gas, which has escaped unchanged from the combustion, is carried through a third tube 28, 29, of deliquescent salts, to deprive it of any moisture it may have acquired in the bottles of alkaline solution and lime-water, and from thence, by the tube 29, 30, into a gasometer, where its quantity is ascertained. Small essays are then taken from it, which are exposed to a solution of sulphuret of potash, to ascertain the proportions of oxygen and azotic gas it contains.

In the combustion of oils, the wick becomes



at last charred, and obstructs the rise of the oil. Besides, if we raise the wick above a certain height, more oil rises through its capillary tubes, than the stream of air is capable of consuming; and smoke is produced. Hence it is necessary to be able to lengthen or shorten the wick without opening the apparatus. This is accomplished by means of the rod 31, 32, 33, 34, which passes through a leather box; and is connected with the support of the wick: and that the motion of this rod, and consequently of the wick, may be regulated with the utmost smoothness and facility, it is moved at pleasure by a pinnion which plays in a toothed rack. The rod, with its appendages, are represented Pl. XII. Fig. 3. It appeared to me, that the combustion would be assisted by surrounding the flame of the lamp with a small glass jar, open at both ends, as represented in its place, in Pl. XI.

I shall not enter into a more detailed description of the construction of this apparatus, which is still capable of being altered and modified in many respects; but shall only add, that when it is to be used in experiments, the lamp and reservoir, with the contained oil, must be accurately weighed; after which it is placed as before directed, and lighted. Having then formed the connection between the air in the gazometer and the lamp, the external jar A, Pl. XI. is fixed over all, and secured by means of the board

BC, and by two rods of iron which connect this board with the lid, and are screwed to it. A small quantity of oil is burnt, while the jar is adjusting to the lid, and the product of that combustion is lost. There is likewise a small portion of air from the gazometer lost at the same time. Both of these are of very inconsiderable consequence in extensive experiments: and they are even capable of being valued in our calculation of the results.

In a particular memoir, I shall give an account to the Academy, of the difficulties inseparable from this kind of experiments. These are so insurmountable and troublesome, that I have not hitherto been able to obtain any rigorous determination of the quantities of the products. I have sufficient proof, however, that the fixed oils are entirely resolved, during combustion, into water and carbonic acid gas, and consequently that they are composed of hydrogen and carbon. But I have no certain knowledge respecting the proportions of these ingredients.

## S E C T. V.

*Of the Combustion of Alkohol.*

The combustion of alkohol may be very readily performed in the apparatus already described for the combustion of charcoal and phosphorus. A lamp, filled with alkohol, is placed under the jar A, Pl. IV. Fig. 3. and a small morsel of phosphorus upon the wick of the lamp, which is set on fire by means of the hot iron, as before directed. This process is, however, liable to considerable inconveniency. It is dangerous to make use of oxygen gas at the beginning of the experiment, for fear of deflagration, which is even liable to happen when common air is employed. An accident of this kind had very nearly proved fatal to myself, in presence of some members of the Academy. Instead of preparing the experiment, as usual, at the time it was to be performed, I had disposed every thing in order the evening before. The atmospheric air of the jar had thereby sufficient time to dissolve a good deal of the alkohol: and this evaporation had even been considerably promoted by the height of the column of mercury, which I had raised to EF, Pl. IV. Fig. 3. The moment I attempt-

ed to set the little morsel of phosphorus on fire, by means of the red hot iron, a violent explosion took place, which threw the jar with great violence against the floor of the laboratory, and dashed it in a thousand pieces.

Hence we can only operate upon very small quantities, such as ten or twelve grains of alkohol, in this manner: and the errors which may be committed in experiments upon such small quantities, prevent our placing any confidence in their results. I endeavoured to prolong the combustion, in the experiments contained in the *Memoirs of the Academy* for 1784, p. 593, by lighting the alkohol first in common air, and furnishing oxygen gas afterwards to the jar in proportion as it consumed. But the carbonic acid gas, produced by the process, became a great hindrance to the combustion, the more so as alkohol is but difficultly combustible, especially in worse than common air; so that even in this way very small quantities only could be burnt.

Perhaps this combustion might succeed better in the oil apparatus, Pl. XI.; but I have not hitherto ventured to try it. The jar A, in which the combustion is performed, is near 1400 cubical inches in dimension: and, were an explosion to take place in such a vessel, its consequences would be very terrible, and very difficult to guard against. I have not, however, despaired of making the attempt.

In consequence of these difficulties, I have been hitherto obliged to confine myself to experiments upon very small quantities of alkohol, at least to combustions made in open vessels, such as that represented in Pl. IX. Fig. 5. which will be described in Section VII. of this chapter. If I am ever able to remove these difficulties, I shall resume this investigation.

## SECTION VI

### *Of the Combustion of Ether.*

Though the combustion of ether in close vessels does not present the same difficulties as that of alkohol, yet it involves some of a different kind, not more easily overcome, and which still prevent the progress of my experiments. I endeavoured to profit by the property which ether possesses, of dissolving in atmospheric air, and being thereby rendered inflammable without explosion. For this purpose, I constructed the reservoir of ether, *abcd*, Pl. VII. 8. to which air is brought from the gazometer, by the tube 1, 2, 3, 4. This air spreads, in the first place, in the double lid *ac* of the reservoir, from which it passes through seven tubes *ef*, *gh*, *ik*, &c. which descend to the bottom of the ether; and it is

forced, by the pressure of the gazometer, to boil up through the ether in the reservoir. We may replace the ether in this first reservoir, in proportion as it is dissolved and carried off by the air, by means of the supplementary reservoir E, connected by a brass tube fifteen or eighteen inches long, and shut by a stop-cock. This length of the connecting tube is to enable the descending ether to overcome the resistance, occasioned by the pressure of the air from the gazometer.

The air, thus loaded with vapours of ether, is conducted by the tube 5, 6, 7, 8, 9, to the jar A, into which it is allowed to escape through a capillary opening, at the extremity of which it is set on fire. The air, when it has served the purpose of combustion, passes through the bottle 16, Pl. XI. the worm 17, 18, and the deliquescent tube 19, 20; after which it passes through the alkaline bottles. In these its carbonic acid gas is absorbed, the water formed during the experiment having been previously deposited in the former parts of the apparatus.

When I caused this apparatus to be constructed, I supposed that the combination of atmospheric air and ether formed in the reservoir *a b c d*, Pl. XII. Fig. 8. was in proper proportion for supporting combustion. But in this I was mistaken; for there is a very considerable quantity of excess of ether; so that an additional quantity of atmo-



spheric air is necessary to enable it to burn fully. Hence a lamp, constructed upon these principles, will burn in the open air, which furnishes the quantity of oxygen necessary for combustion, but will not burn in close vessels in which the air is not renewed. Owing to this circumstance, my ether lamp went out, soon after being lighted and shut up in the jar A, Pl. XII. Fig. 8. To remedy this defect, I endeavoured to bring atmospheric air to the lamp, by the lateral tube, 10, 11, 12, 13, 14, 15, which I distributed circularly round the flame. But the flame is so exceedingly rare, that it is blown out by the gentlest possible stream of air; so that I have not hitherto succeeded in burning ether. I do not, however, despair of being able to accomplish it by means of some changes I am about to have made upon this apparatus.

## S E C T. VII.

### *Of the Combustion of Hydrogen Gas, and the Formation of Water.*

In the formation of water, two substances, hydrogen and oxygen, which are both in the aëriform state before combustion, are transformed into a liquid, or water, by the operation.

This experiment would be very easy, and would only require very simple instruments, if it were possible to procure the two gasses perfectly pure, so that they might burn without any residuum. We might, in that case, operate in very small vessels, and, by continually furnishing the two gasses in proper proportions, might continue the combustion indefinitely. But, hitherto, chemists have only employed impure oxygen gas, mixed with azotic gas; from which circumstance they have only been able to keep up the combustion of hydrogen gas for a very limited time, in close vessels; because, as the residuum of azotic gas is continually increasing, the air becomes at last so much contaminated, that the flame weakens and goes out. This inconvenience is so much the greater in proportion as the oxygen gas employed is less pure. From this circumstance, we must either be satisfied with operating upon small quantities, or must exhaust the vessels at intervals, to get rid of the residuum of azotic gas. But, in this case, a portion of the water formed during the experiment, is evaporated by the exhaustion: and the resulting error is the more dangerous to the accuracy of the process, as we have no certain means of ascertaining its value.

These considerations make me desirous to repeat the principal experiments of pneumatic chemistry, with oxygen gas, entirely free from

any admixture of azotic gas : and this may be procured from oxygenated muriat of potash. The oxygen gas extracted from this salt does not appear to contain azot, unless accidentally ; so that by proper precautions, it may be obtained perfectly pure. In the mean time, the apparatus employed by Mr Meufnier and me, for the combustion of hydrogen gas, which is described in the experiment for recombination of water, Part I. Chap. VIII. and need not therefore be here repeated, will answer the purpose. When pure gasses are procured, this apparatus will require no alterations, except that the capacity of the vessels may then be diminished. See Pl. IV. Fig. 5.

The combustion, when once begun, continues for a considerable time ; but weakens gradually, in proportion as the quantity of azotic gas, remaining from the combustion, increases, till at last the azotic gas is in such over proportion, that the combustion can no longer be supported ; and the flame goes out. This spontaneous extinction must be prevented ; because, as the hydrogen gas is pressed upon in its reservoir, by an inch and a half of water, while the oxygen gas suffers a pressure only of three lines, a mixture of the two would take place in the balloon, which would at last be forced, by the superior pressure, into the reservoir of oxygen gas : Wherefore the combustion must be stop-

ped, by shutting the stop-cock of the tube *d Dd* whenever the flame grows very feeble ; for which purpose it must be attentively watched.

There is another apparatus for combustion, which, though we cannot with it perform experiments with the same scrupulous exactness as with the preceding instruments, gives very striking results, which are extremely proper to be shewn in courses of philosophical chemistry. It consists of a worm *EF*, Pl. IX. Fig. 5. contained in a metallic cooler *ABCD*. To the upper part of this worm *E*, the chimney *GH* is fixed, which is composed of two tubes, the inner of which is a continuation of the worm ; and the outer one is a case of tin-plate, which surrounds it at about an inch distance, and the interval is filled up with sand. At the inferior extremity *K* of the inner tube, a glass tube is fixed, to which we adopt the Argand lamp *LM* for burning alkohol, &c.

Things being thus disposed, and the lamp being filled with a determinate quantity of alkohol, it is set on fire. The water which is formed during the combustion, rises in the chimney *KE* ; and being condensed in the worm, runs out at its extremity *F* into the bottle *P*. The double tube of the chimney, filled with sand in the interstice, is to prevent the tube from cooling in its upper part, and condensing the water ; otherwise, it would fall back in the tube, and we should not be able to ascertain its quantity : and

besides it might fall in drops upon the wick, and extinguish the flame. The intention of this construction, is to keep the chimney always hot, and the worm always cool, that the water may be preserved in the state of vapour while rising, and may be condensed immediately upon getting into the descending part of the apparatus. By this instrument, which was contrived by Mr Meusnier, and which is described by me in the Memoirs of the Academy for 1784, p. 593, we may, with attention to keep the worm always cold, collect nearly seventeen ounces of water from the combustion of sixteen ounces of alcohol.

## S E C T. VIII.

### *Of the Oxydation of Metals.*

The term *oxydation*, or *calcination*, is chiefly used to signify the process by which metals, exposed to a certain degree of heat, are converted into oxyds, by absorbing oxygen from the air. This combination takes place in consequence of oxygen possessing a greater affinity to metals, at a certain temperature, than to caloric, which

becomes disengaged in its free state. But, as this disengagement, when made in common air, is slow and progressive, it is scarcely evident to the senses. It is quite otherwise, however, when oxydation takes place in oxygen gas: for, being produced with much greater rapidity, it is generally accompanied with heat and light, so as evidently to shew that metallic substances are real combustible bodies.

All the metals have not the same degree of affinity to oxygen. Gold, silver, and platina, for instance, are incapable of taking it away from its combination with caloric, even in the greatest known heat: whereas the other metals absorb it in a larger or smaller quantity, until the affinities of the metal to oxygen, and of the latter to caloric, are in exact equilibrium. Indeed, this state of equilibrium of affinities may be assumed as a general law of nature in all combinations.

In all operations of this nature, the oxydation of metals is accelerated by giving free access to the air. It is sometimes much assisted by joining the action of bellows, so contrived as to direct a stream of air over the surface of the metal. This process becomes greatly more rapid, if a stream of oxygen gas be used, which may be readily done by means of the gazometer formerly described. The metal, in this case, throws out a brilliant flame, and the oxydation is very quickly accom-



plished. But this method can only be used in very confined experiments, on account of the expence of procuring oxygen gas. In the essay of ores, and in all the common operations of the laboratory, the calcination or oxydation of metals is usually performed in a dish of baked clay, Pl. IV. Fig. 6. commonly called a *roasting test*, placed in a strong furnace. The substances to be oxydated are frequently stirred, on purpose to present fresh surfaces to the air.

Whenever this operation is performed upon a metal which is not volatile, and from which nothing flies off into the surrounding air during the process, the metal acquires additional weight. But the cause of this increased weight during oxydation could never have been discovered by means of experiments performed in free air: and it is only since these operations have been performed in close vessels, and in determinate quantities of air, that any just conjectures have been formed concerning the cause of this phenomenon. The first method for this purpose is due to Dr Priestley, who exposes the metal to be calcined in a porcelain cup N, Pl. IV. Fig. 11. placed upon the stand IK, under a jar A, in the basin BCDE, full of water: the water is made to rise up to GH, by sucking out the air with a syphon, and the focus of a burning glass is made to fall upon the metal. In a few minutes, the

oxydation takes place, a part of the oxygen contained in the air combines with the métal ; and a proportional diminution of the volume of air is produced. What remains, is nothing more than azotic gas, still, however, mixed with a small quantity of oxygen gas. I have given an account of a series of experiments, made with this apparatus, in my *Physical and Chemical Essays*, first published in 1773. Mercury may be used instead of water in this experiment, whereby the results are rendered still more conclusive.

Another process for this purpose was invented by Mr Boyle, of which I gave an account in the *Memoirs of the Academy* for 1774, p. 351. The metal is introduced into a retort, Pl. III. Fig. 20. the beak of which is hermetically sealed. The metal is then oxydated, by means of heat applied with great precaution. The weight of the vessel, and its contained substances, is not at all changed by this process, until the extremity of the neck of the retort is broken : but, when that is done, the external air rushes in with a hissing noise. This operation is attended with danger, unless a part of the air be driven out of the retort, by means of heat, before it is hermetically sealed ; as, otherwise, the retort would be apt to burst by the dilatation of the air, when placed in the furnace. The quantity of air driven out, may be received under a jar in the pneumato-chemical appara-

tus, by which its quantity, and that of the air remaining in the retort, is ascertained. I have not multiplied my experiments upon oxydation of metals, so much as I could have wished : neither have I obtained satisfactory results with any metal except tin. It is much to be wished, that some person would undertake a series of experiments upon the oxydation of metals in the several gasses. The subject is important, and would fully repay any trouble which this kind of experiment might occasion.

As all the oxyds of mercury are capable of revivifying without addition, and restore the oxygen gas they had before absorbed, this seemed to be the most proper metal for becoming the subject of conclusive experiments upon oxydation. I formerly endeavoured to accomplish the oxydation of mercury in close vessels, by filling a retort, containing a small quantity of mercury, with oxygen gas, and adapting a bladder half full of the same gas to its beak ; see Pl. IV. Fig. 12. Afterwards, by heating the mercury in the retort for a very long time, I succeeded in oxydating a very small portion so as to form a little red oxyd floating upon the surface of the running mercury. But the quantity was so small, that the smallest error committed in the determination of the quantities of oxygen gas, before and after the operation, must have thrown very great uncertainty upon the

results of the experiment. I was, besides, dissatisfied with this process, and not without cause, lest any air might have escaped through the pores of the bladder, more especially as it becomes shrivelled by the heat of the furnace, unless covered over with cloths kept constantly wet.

This experiment is performed with more certainty in the apparatus described in the *Memoirs of the Academy* for 1775, p. 580. This consists of a retort A, Pl. IV. Fig. 2. having a crooked glass tube BCDE of ten or twelve lines internal diameter, melted on to its beak, and which is engaged under the bell glass FG, standing with its mouth downwards, in a basin filled with water or mercury. The retort is placed upon the bars of the furnace MMNN, Pl. IV. Fig. 2. or in a sand bath: and by means of this apparatus we may, in the course of several days, oxydate a small quantity of mercury in common air. The red oxyd floats upon the surface, from which it may be collected and revived, so as to compare the quantity of oxygen gas obtained in revivification with the absorption which took place during oxydation. This kind of experiment can only be performed upon a small scale, so that no very certain conclusions can be drawn from it\*.

\* See an account of this experiment, Part I. Chap. iii.—A.

The combustion of iron, in oxygen gas, being a true oxydation of that metal, ought to be mentioned in this place. The apparatus employed by Mr Ingenhoufz for this operation, is represented in Pl. IV. Fig. 17.; but, having already described it sufficiently in Chap. III. I shall refer the reader to what is said of it in that place. Iron may likewise be oxydated by combustion, in vessels filled with oxygen gas, in the way already directed for phosphorus and charcoal. This apparatus is represented Pl. IV. Fig. 3. and described in the fifth chapter of the first part of this work. We learn from Mr Ingenhoufz, that all the metals, except gold, silver, and mercury, may be burnt or oxydated in the same manner, by reducing them into very fine wire, or very thin plates cut into narrow slips. These are twisted round with iron-wire, which communicates the property of burning to the other metals.

Mercury is even difficultly oxydated in free air. In chemical laboratories, this process is usually carried on in a matrafs A, Pl. IV. Fig. 10. having a very flat body, and a very long neck BC, which vessel is commonly called *Boyle's bell*. A quantity of mercury is introduced, sufficient to cover the bottom: and it is placed in a sand-bath, which keeps up a constant heat approaching to that of boiling mercury. By continuing this operation with five or six simi-

lar matraffes during feveral months, and renewing the mercury from time to time, a few ounces of red oxyd are at laft obtained. The great flownefs and inconvenience of this apparatus arife from the air not being fufficiently renewed : but if, on the other hand, too free a circulation were given to the external air, it would carry off the mercury in folution in the ftate of vapour, fo that in a few days none would remain in the veffel.

As, of all the experiments upon the oxydation of metals, thofe with mercury are the moft conclufive, it were much to be wifhed, that a fimple apparatus could be contrived, by which this oxydation and its results might be demonftrated in public courfes of chemistry. This might, in my opinion, be accomplifhed by methods fimilar to thofe I have already defcribed, for the combuftion of charcoal and the oils. But, owing to other purfuits, I have not been able hitherto to refume this kind of experiment.

The oxyd of mercury revives without addition, by being heated to a flightly red heat. In this degree of temperature, oxygen has greater affinity to caloric than to mercury ; and forms oxygen gas. This is always mixed with a fmall portion of azotic gas, which indicates that the mercury abforbs a fmall portion of this latter gas during oxydation. It almoft always contains a little carbonic acid gas, which muft un-



doubtedly be attributed to the foulnesses of the oxyd. These are cleared by the heat, and convert a part of the oxygen gas into carbonic acid.

If chemists were reduced to the necessity of procuring all the oxygen gas, employed in their experiments, from mercury oxydated by heat without addition, or, as it is called, *calcined* or *precipitated* per se, the excessive dearness of that preparation would render experiments, even upon a moderate scale, quite impracticable. But mercury may likewise be oxydated by means of nitric acid : and in this way we procure a red oxyd, even more pure than that produced by calcination. I have sometimes prepared this oxyd by dissolving mercury in nitric acid, evaporating to dryness, and calcining the salt, either in a retort, or in capsules formed of pieces of broken matraffes and retorts, in the manner formerly described. But I have never succeeded in making it equally beautiful with what is sold by the druggists, and which is, I believe, brought from Holland. In choosing this, we ought to prefer what is in solid lumps composed of soft adhering scales ; as, when in powder, it is sometimes adulterated with red oxyd of lead.

To obtain oxygen gas from the red oxyd of mercury, I usually employ a porcelain retort, having a long glass tube adapted to its beak,

which is engaged under jars in the water pneumato-chemical apparatus: and I place a bottle in the water, at the end of the tube, for receiving the mercury, in proportion as it revives and distils over. As the oxygen gas never appears till the retort becomes red, it seems to prove the principle established by Mr Berthollet, that an obscure heat can never form oxygen gas, and that light is one of its constituent elements. We must reject the first portion of gas which comes over, as being mixed with common air, from what was contained in the retort at the beginning of the experiment. But, even with this precaution, the oxygen gas procured is usually contaminated with a tenth part of azotic gas, and with a very small portion of carbonic acid gas. This latter is readily got rid of, by making the gas pass through a solution of caustic alkali: but we know of no method for separating the azotic gas. Its proportions may, however, be ascertained by leaving a known quantity of the oxygen gas contaminated with it for a fortnight, in contact with sulphuret of soda or potash, which absorbs the oxygen gas, and converts the sulphur into sulphuric acid, leaving the azotic gas pure.

We may likewise procure oxygen gas from black oxyd of manganese, or from nitrat of potash, by exposing them to a red heat, in the apparatus already described for operating upon red

oxyd of mercury: only, as it requires such a heat as is at least capable of softening glass, we must employ retorts of stone or of porcelain. But the purest and best oxygen gas is what is disengaged from oxygenated muriat of potash, by simple heat. This operation is performed in a glass retort, and the gas obtained is perfectly pure, provided that the first portions, which are mixed with the common air of the vessels, be rejected.

## C H A P. IX.

*Of Deflagration.*

I HAVE already shewn, Part. I. Chap. IX. that oxygen does not always part with the whole of the caloric it contained in the state of gas, when it enters into combination with other bodies. It carries almost the whole of its caloric along with it, on entering into the combinations which form nitric acid and oxygenated muriatic acid; so that in nitrats, and more especially in oxygenated muriats, the oxygen is, in a certain degree, in the state of oxygen gas, condensed, and reduced to the smallest volume it is capable of occupying.

In these combinations, the caloric exerts a constant action upon the oxygen, to bring it back to the state of gas. Hence the oxygen adheres but very slightly; and the smallest additional force is capable of setting it free: and, when such force is applied, it often recovers the state of gas instantaneously. This rapid passage from the solid to the aëriform state, is called detonation, or fulmination, because it is usually accompanied with noise and explosion. Deflagrations are commonly produced by means of combinations of charcoal, either with nitre or

with oxygenated muriat of potash : sometimes, to assist the inflammation, sulphur is added ; and, upon the just proportion of these ingredients, and the proper manipulation of the mixture, the art of making gunpowder depends.

As oxygen is changed, by deflagration with charcoal, into carbonic acid, instead of oxygen gas, carbonic acid gas is disengaged, at least when the mixture has been made in just proportions. In deflagration with nitre, azotic gas is likewise disengaged ; because azot is one of the constituent elements of nitric acid.

The sudden and instantaneous disengagement and expansion of these gasses is not, however, sufficient for explaining all the phenomena of deflagration ; because, if this were the sole operating power, gunpowder would always be so much the stronger in proportion as the quantity of gas disengaged in a given time was the more considerable, which does not always accord with experiment. I have tried some kinds which produced almost double the effect of ordinary gunpowder, although they gave out a sixth part less of gas during deflagration. It would appear, that the quantity of caloric disengaged at the moment of detonation, contributes considerably to the expansive effects produced ; for, although caloric penetrates freely through the pores of every body in nature, it can only do so progressively, and in a given time. Hence, when the quantity disenga-

ged at once is too large to get through the pores of the surrounding bodies, it must necessarily act in the same way with ordinary elastic fluids, and must overturn every thing that opposes its passage. This must, at least in part, take place when gunpowder is set on fire in a cannon; as, although the metal is permeable to caloric, the quantity disengaged at once is too large to find its way through the pores of the metal: it must therefore make an effort to escape on every side; and, as the resistance all round, excepting towards the muzzle, is too great to be overcome, this effort is necessarily employed for expelling the bullet.

The caloric produces a second effect, by means of the repulsive force exerted between its particles. It causes the gases, disengaged at the moment of deflagration, to expand with a degree of force proportioned to the temperature produced.

It is very probable, that water is decomposed during the deflagration of gunpowder, and that part of the oxygen furnished to the nascent carbonic acid gas is produced from it. If so, a considerable quantity of hydrogen gas must be disengaged in the instant of deflagration, which expands, and contributes to the force of the explosion. It may readily be conceived, how greatly this circumstance must increase the effect of powder, if we consider that a pint of hydrogen



gas weighs only one grain and two thirds. Hence a very small quantity in weight must occupy a very large space: and it must exert a prodigious expansive force in passing from the liquid to the aëriform state of existence.

In the last place, as a portion of undecomposed water is reduced to vapour during the deflagration of gunpowder, and as water, in the state of gas, occupies seventeen or eighteen hundred times more space than in its liquid state, this circumstance must likewise contribute largely to the explosive force of the powder.

I have already made a considerable series of experiments upon the nature of the elastic fluids disengaged during the deflagration of nitre with charcoal and sulphur, and have made some, likewise, with the oxygenated muriat of potash. This method of investigation leads to tolerably accurate conclusions with respect to the constituent elements of these salts. Some of the principal results of these experiments, and of the consequences drawn from them respecting the analysis of nitric acid, are reported in the collection of memoirs presented to the Academy by foreign philosophers, vol. xi. p. 625. Since then I have procured more convenient instruments, and I intend to repeat these experiments upon a larger scale, by which I shall procure more accurate precision in their results. The following, however, is the process I have hither-

to employed. I would very earnestly advise such as intend to repeat some of these experiments, to be very much upon their guard in operating upon any mixture which contains nitre, charcoal and sulphur, and more especially with those in which oxygenated muriat of potash is mixed with these two materials.

I make use of pistol barrels, about six inches long, and of five or six lines diameter, having the touch-hole spiked up with an iron nail strongly driven in, and broken in the hole, and a little tin-smiths folder run in to prevent any possible issue for the air. These are charged with a mixture of known quantities of nitre and charcoal, or any other mixture capable of deflagration, reduced to an impalpable powder, and formed into a paste with a moderate quantity of water. Every portion of the materials introduced, must be rammed down with a rammer nearly of the same caliber with the barrel. Four or five lines at the muzzle must be left empty; and about two inches of quick match are added at the end of the charge. The only difficulty in this experiment, especially when sulphur is contained in the mixture, is to discover the proper degree of moistening; for, if the paste be too much wetted, it will not take fire; and if too dry, the deflagration is apt to become too rapid, and even dangerous.

When the experiment is not intended to be rigorously exact, we set fire to the match; and, when it is just about to communicate with the charge, we plunge the pistol below a large bell-glass full of water, in the pneumato-chemical apparatus. The deflagration begins, and continues in the water; and gas is disengaged with less or more rapidity, in proportion as the mixture is more or less dry. So long as the deflagration continues, the muzzle of the pistol must be kept somewhat inclined downwards to prevent the water from getting into its barrel. In this manner I have sometimes collected the gas produced from the deflagration of an ounce and half, or two ounces, of nitre.

In this manner of operating, it is impossible to determine the quantity of carbonic acid gas disengaged; because a part of it is absorbed by the water while passing through it. But, when the carbonic acid is absorbed, the azotic gas remains; and, if it be agitated for a few minutes in caustic alkaline solution, we obtain it pure, and can easily determine its volume and weight. We may even, in this way, acquire a tolerably exact knowledge of the quantity of carbonic acid, by repeating the experiment a great many times, and varying the proportions of charcoal, till we find the exact quantity requisite to deflagrate the whole nitre employed. Hence, by means of the weight of charcoal employed, we

determine the weight of oxygen necessary for saturation, and deduce the quantity of oxygen contained in a given weight of nitre.

I have used another process, by which the results of this experiment are considerably more accurate, which consists in receiving the disengaged gasses in bell-glasses filled with mercury. The mercurial apparatus I employ is large enough to contain jars of from twelve to fifteen pints in capacity, which are not very readily managed when full of mercury; and even require to be filled by a particular method. When the jar is placed in the cistern of mercury, a glass syphon is introduced, connected with a small air-pump, by means of which the air is exhausted, and the mercury rises so as to fill the jar. After this, the gas of the deflagration is made to pass into the jar, in the same manner as directed when water is employed.

I must again repeat, that this species of experiment requires to be performed with the greatest possible precautions. I have sometimes seen, when the disengagement of gas proceeded with too great rapidity, jars filled with more than an hundred and fifty pounds of mercury, driven off by the force of the explosion, and broken to pieces, while the mercury was scattered about in great quantities.

When the experiment has succeeded, and the gas is collected under the jar, its quantity in

general, and the nature and quantities of the several species of gasses of which the mixture is composed, are accurately ascertained by the methods already pointed out, in the second chapter of this part of my work. I have been prevented from putting the last hand to the experiments I have begun upon deflagration, from their connection with the objects I am at present engaged in ; and I am in hopes they will throw considerable light upon the operations belonging to the manufacture of gunpowder.

## CHAP. X.

*Of the Instruments necessary for Operating upon  
Bodies in very high Temperatures.*

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## S E C T. I.

*Of Fusion.*

WE have already seen, that, by aqueous solution, in which the particles of bodies are separated from each other, neither the solvent, nor the body held in solution, are at all decomposed; so that, whenever the cause of separation ceases, the particles reunite, and the saline substance recovers precisely the same appearance and properties it possessed before solution. Real solutions are produced by fire, or by introducing and accumulating a great quantity of caloric between the particles of bodies: and this species of solution in caloric is usually called *fusion*.

This operation is commonly performed in vessels called crucibles, which must necessarily

Y y y



be less fusible than the bodies they are intended to contain. Hence, in all ages, chemists have been extremely solicitous to procure crucibles of very refractory materials, or such as are capable of resisting a very high degree of heat. The best are made of very pure clay, or of porcelain earth: whereas such as are made of clay, mixed with calcareous or silicious earth, are very fusible. All the crucibles made in the neighbourhood of Paris are of this kind; and are consequently unfit for most chemical experiments. The Hessian crucibles are tolerably good: but the best are made of Limoges earth, which seems absolutely infusible. We have, in France, a great many clays very fit for making crucibles; such, for instance, is the kind used for making melting-pots, at the glass manufactory of St Gobin.

Crucibles are made of various forms, according to the operations they are intended to perform. Several of the most common kinds are represented Pl. VII. Fig. 7, 8, 9, and 10. The one represented at Fig. 9. is almost shut at its mouth.

Though fusion may often take place without changing the nature of the fused body, this operation is frequently employed as a chemical means of decomposing and recombining bodies. In this way all the metals are extracted from their ores: and, by this process, they are revived,

moulded, and alloyed with each other. By this process sand and alkali are combined to form glass; and by it likewise pastes, or coloured stones, enamels, &c. are formed.

The action of violent fire was much more frequently employed by the ancient chemists than it is in modern experiments. Since greater precision has been employed in philosophical researches, the *humid* has been preferred to the *dry* method of process: and fusion is seldom referred to until all the other means of analysis have failed.

## S E C T. II.

### *Of Furnaces.*

These are instruments of most universal use in chemistry: and, as the success of a great number of experiments depends upon their being well or ill constructed, it is of great importance, that a laboratory be well provided in this respect. A furnace is a kind of hollow cylindrical tower, sometimes widened above, Pl. XIII, Fig. 1. ABCD, which must have at least two lateral openings; one in its upper part F, which is the door of the fire place, and one below, G,

leading to the ash-hole. Between these, the furnace is divided by a horizontal grate, intended for supporting the fuel, the situation of which is marked in the figure by the line *HI*. Though this is the least complicated of all the chemical furnaces, yet it is applicable to a great number of purposes. By it, lead, tin, bismuth, and, in general, every substance which does not require a very strong fire, may be melted in crucibles. It will serve for metallic oxydations, for evaporatory vessels, and for sand baths, as in *Pl. III. Fig. 1. and 2.* To render it proper for these purposes, several notches, *m m m m*, *Pl. 3 III. Fig. 1.* are made in its upper edge; as, otherwise, any pan, which might be placed over the fire, would stop the passage of the air, and prevent the fuel from burning. This furnace can only produce a moderate degree of heat; because the quantity of charcoal it is capable of consuming, is limited by the quantity of air which is allowed to pass through the opening *G* of the ash-hole. Its power might be considerably augmented by enlarging this opening: but then the great stream of air, which is convenient for some operations, might be hurtful in others: wherefore we must have furnaces of different forms, constructed for different purposes, in our laboratories. There ought especially to be several of the kind now described, of different sizes.

The reverberatory furnace, *Pl. XIII. Fig. 2.*

is perhaps more necessary. This, like the common furnace, is composed of the ash-hole HIKL, the fire-place KLMN, the laboratory MNOP, and the dome RRSS with its funnel or chimney TTVV; and to this last several additional tubes may be adapted, according to the nature of the different experiments. The retort A is placed in the division called the laboratory, and is supported by two bars of iron, which run across the furnace: and its beak comes out at a round hole in the side of the furnace, one half of which is cut in the piece called the laboratory, and the other in the dome. In most of the ready-made reverberatory furnaces, which are sold by the potters at Paris, the openings both above and below are too small: they do not allow a sufficient volume of air to pass through; hence, as the quantity of charcoal consumed, or, what is much the same thing, the quantity of caloric disengaged, is nearly in proportion to the quantity of air which passes through the furnace, these furnaces do not produce a sufficient effect in a great number of experiments. To remedy this defect, there ought to be two openings GG to the ash-hole. One of these is shut up when only a moderate fire is required: and both are kept open when the strongest power of the furnace is to be exerted. The opening of the dome SS ought

likewise to be considerably larger than is usually made.

It is of great importance not to employ retorts of too large size in proportion to the furnace, as a sufficient space ought always to be allowed for the passage of the air between the sides of the furnace and the vessel. The retort A in the figure is too small for the size of the furnace ; yet I find it more easy to point out the error than to correct it. The intention of the dome is to oblige the flame and heat to surround and strike back or reverberate upon every part of the retort, whence the furnace gets the name of reverberatory. Without this circumstance the retort would only be heated in its bottom, the vapours raised from the contained substance would condense in the upper part, and a continual cohabitation would take place without any thing passing over into the receiver ; but, by means of this dome, the retort is equally heated in every part, and the vapours being forced out, can only condense in the neck of the retort, or in the recipient.

To prevent the bottom of the retort from being either heated or cooled too suddenly, it is sometimes placed in a small sand-bath of baked clay, standing upon the cross bars of the furnace. Likewise, in many operations, the retorts are coated over with lutes, some of which are intended to preserve them from the too sudden

influence of heat or of cold, while others are for sustaining the glass, or forming a kind of second retort, which supports the glass one during operations wherein the strength of the fire might soften it. The former is made of brick-clay, with a little cow's hair beat up with it, into a paste or mortar, and spread over the glass or stone retorts. The latter is made of pure clay and pounded stone-ware mixed together, and used in the same manner. This dries and hardens by the fire, so as to form a true supplementary retort, capable of retaining the materials if the glass retort below should crack or soften. But, in experiments which are intended for collecting gasses, this lute, being porous, is of no manner of use.

In a great many experiments, wherein very violent fire is not required, the reverberatory furnace may be used as a melting one, by leaving out the piece called the laboratory, and placing the dome immediately upon the fire-place, as represented Pl. XIII. fig. 3. The furnace, represented in Fig 4. is very convenient for fusions. It is composed of the fire-place and ash-hole ABD, without a door, and having a hole E, which receives the muzzle of a pair of bellows strongly luted on, and the dome ABGH, which ought to be rather lower than is represented in the figure. This furnace is not capable of producing a very strong heat; but is



sufficient for ordinary operations, and may be readily moved to any part of the laboratory where it is wanted. Though these particular furnaces are very convenient, every laboratory must be provided with a forge furnace, having a good pair of bellows, or, what is more necessary, a powerful melting furnace. I shall describe the one I use, with the principles upon which it is constructed.

The air circulates in a furnace in consequence of being heated in its passage through the burning coals. It dilates; and, becoming lighter than the surrounding air, is forced to rise upwards by the pressure of the lateral columns of air; and is replaced by fresh air from all sides, especially from below. This circulation of air even takes place when coals are burnt in a common chaffing dish. But we can readily conceive, that, in a furnace, open on all sides, the mass of air which passes, all other circumstances being equal, cannot be so great as when it is obliged to pass through a furnace in the shape of a hollow tower, like most of the chemical furnaces; and consequently, that the combustion must be more rapid in a furnace of this latter construction. Suppose, for instance, the furnace ABCDEF open above, and filled with burning coals, the force, with which the air passes through the coals, will be in proportion to the difference between the specific gravity of two columns

equal to AC, the one of cold air without, and the other of heated air within the furnace. There must be some heated air above the opening AB: and the superior levity of this ought likewise to be taken into consideration. But, as this portion is continually cooled and carried off by the external air, cannot produce any great effect.

But, if we add to this furnace a large hollow tube GHAB of the same diameter, which preserves the air, which has been heated by the burning coals, from being cooled and dispersed by the surrounding air, the difference of specific gravity, which causes the circulation, will then be between two columns equal to GC. Hence, if GC be three times the length of AC, the circulation will have treble force. This is upon the supposition, that the air in GHCD is as much heated as what is contained in ABCD, which is not strictly the case; because the heat must decrease between AB and GH: but, as the air in GHAB is much warmer than the external air, it follows, that the addition of the tube must increase the rapidity of the stream of air: that a larger quantity must pass through the coals; and consequently, that a greater degree of combustion must take place.

We must not, however, conclude from these principles, that the length of this tube ought to be indefinitely prolonged; for, since the heat of

Z. z z

the air gradually diminishes in passing from AB to GH, even from the contact of the sides of the tube, if the tube were prolonged to a certain degree, we would at last come to a point where the specific gravity of the included air would be equal to the air without : and, in this case, as the cool air would no longer tend to rise upwards, it would become a gravitating mass, resisting the ascension of the air below. Besides, as this air, which has served for combustion, is necessarily mixed with carbonic acid gas, which is considerably heavier than common air, if the tube were made long enough, the air might at last approach so near to the temperature of the external air, as even to gravitate downwards. Hence we must conclude, that the length of the tube added to a furnace, must have some limit, beyond which it weakens, instead of strengthening, the force of the fire.

From these reflections it follows, that the first foot of tube added to a furnace produces more effect than the sixth, and the sixth more than the tenth. But we have no data to ascertain at what height we ought to stop. This limit of useful addition is so much the farther in proportion as the materials of the tube are weaker conductors of heat, because the air will thereby be so much less cooled : hence baked earth is much preferable to plate iron. It would be even of consequence to make the tube double, and

to fill the interval with rammed charcoal, which is one of the worst known conductors of heat. By this the refrigeration of the air will be retarded, and the rapidity of the stream of air consequently increased: and, by this means, the tube may be made so much the longer.

As the fire-place is the hottest part of a furnace, and the part where the air is most dilated in its passage, this part ought to be made with a considerable widening or belly. This is the more necessary, as it is intended to contain the charcoal and crucible, as well as for the passage of the air which supports, or rather produces the combustion. Hence we only allow the interstices between the coals for the passage of the air.

On these principles my melting furnace is constructed, which I believe is at least equal in power to any hitherto made: though I by no means pretend that it possesses the greatest possible intensity that can be produced in chemical furnaces. The augmentation of the volume of air produced during its passage through a melting furnace, not being hitherto ascertained from experiment, we are still unacquainted with the proportions which should exist between the inferior and superior apertures: and the absolute size, of which these openings should be made, is still less understood. Hence data are wanting by which to proceed upon principle: and we

can only accomplish the end in view by repeated trials.

This furnace, which, according to the above-stated rules, is in form of an elliptical spheroid, is represented Pl. XIII. Fig. 6. ABCD. It is cut off at the two ends by two plains, which pass, perpendicular to the axis, through the foci of the ellipse. From this shape it is capable of containing a considerable quantity of charcoal, while it leaves sufficient space in the intervals for the passage of the air. That no obstacle may oppose the free access of external air, it is perfectly open below, after the model of Mr Macquer's melting furnace, and stands upon an iron tripod. The grate is made of flat bars set on edge, and with considerable interstices. To the upper part is added a chimney, or tube, of baked earth, ABFG, about eighteen feet long, and almost half the diameter of the furnace. Though this furnace produces a greater heat than any hitherto employed by chemists, it is still susceptible of being considerably increased in power by the means already mentioned, the principal of which is to render the tube a bad a conductor of heat as possible, by making it double, and filling the interval with rammed charcoal.

When it is required to know if lead contains any mixture of gold or silver it is heated in a strong fire in capsules of calcined bones, which

are called cuppels. The lead is oxydated becomes vitrified, and sinks into the substance of the cuppel; while the gold or silver, being incapable of oxydation, remain pure. As lead will not oxydate without free access of air, this operation cannot be performed in a crucible placed in the middle of the burning coals of a furnace; because the internal air, being mostly already reduced by the combustion into azotic and carbonic acid gas, is no longer fit for the oxydation of metals. It was therefore necessary, to contrive a particular apparatus, in which the metal should be at the same time exposed to the influence of violent heat, and defended from contact with air rendered incombustible by its passage through burning coals.

The furnace intended for answering this double purpose, is called the cuppelling or essay furnace. It is usually made of a square form, as represented Pl. XIII. Fig. 8. and 10. having an ash-hole AABB, a fire-place BBCC, a laboratory CCDD, and a dome DDEF. The muffle or small oven of baked earth GH, Fig. 9. being placed in the laboratory of the furnace, upon cross bars of iron, is adjusted to the opening GG, and luted with clay softened in water. The cuppels are placed in this oven or muffle, and charcoal is conveyed into the furnace through the openings of the dome and fire-place. The external air enters through the openings of the ash-hole for sup-



porting the combustion, and escapes by the superior opening or chimney at EE : and air is admitted through the door of the muffle GG for oxydating the contained metal.

Very little reflection is sufficient to discover the erroneous principles upon which this furnace is constructed. When the opening GG is shut, the oxydation is produced slowly, and with difficulty, for want of air to carry it on : and, when this hole is open, the stream of cold air, which is then admitted, fixes the metal, and obstructs the process. These inconveniences may be easily remedied, by constructing the muffle and furnace in such a manner that a stream of fresh external air should always play upon the surface of the metal : and this air should be made to pass through a pipe of clay kept continually red hot by the fire of the furnace. By this means, the inside of the muffle will never be cooled ; and processes will be finished in a few minutes, which at present require a considerable space of time.

Mr Sage remedies these inconveniences in a different manner. He places the cuppel containing lead, alloyed with gold or silver, among the charcoal of an ordinary furnace, and covered by a small porcelain muffle. When the whole is sufficiently heated, he directs the blast of a common pair of hand-bellows upon the surface

of the metal, and completes the cuppellation in this way with great ease and exactness.

## S E C T. III.

*Of increasing the Action of Fire, by using Oxygen Gas instead of Atmospheric Air.*

By means of large burning glasses, such as those of Tchirnhausen and of Mr de Trudaine, a degree of heat is obtained somewhat greater than has hitherto been produced in chemical furnaces, or even in the ovens of furnaces used for baking hard porcelain. But these instruments are extremely expensive ; and do not even produce heat sufficient to melt crude platina : so that their advantages are by no means sufficient to compensate for the difficulty of procuring, and even of using them. Concave mirrors produce somewhat more effect than burning glasses of the same diameter, as is proved by the experiments of Messrs Macquer and Beaumé with the speculum of the Abbé Bouriot. But, as the direction of the reflected rays is necessarily from below upwards, the substance to be operated upon must be placed in the air, without any support, which renders most chemical experiments impossible to be performed with this instrument.

For these reasons, I first endeavoured to employ oxygen gas in combustion, by filling large bladders with it, and making it pass through a tube capable of being shut by a stop-cock: and in this way I succeeded in causing it to support the combustion of lighted charcoal. The intensity of the heat produced, even in my first attempt, was so great, as readily to melt a small quantity of crude platina. To the success of this attempt is owing the idea of the gazometer, described p. 336. *et seq.* which I substituted instead of the bladders; and, as we can give the oxygen gas any necessary degree of pressure, we can with this instrument keep up a continued stream, and give it even a very considerable force.

The only apparatus necessary for experiments of this kind, consists of a small table, ABCD, Pl. XII. Fig. 15. with a hole F, through which passes a tube of copper or silver, ending in a very small opening at G, and capable of being opened or shut by the stop-cock H. This tube is continued below the table at *l m n o*, and is connected with the interior cavity of the gazometer. When we mean to operate, a hole of a few lines deep, must be made with a chisel in a piece of charcoal, into which the substance to be treated laid, the charcoal is set on fire by means of a candle and blow-pipe; after which it is ex-

posed to a rapid stream of oxygen gas from the extremity G of the tube FG.

This manner of operating can only be used with such bodies as may be placed without inconvenience, in contact with charcoal, such as metals, simple earths, &c. But, for bodies whose elements have affinity to charcoal, and which are consequently decomposed by that substance, such as sulphats, phosphats, and most of the neutral salts, metallic glasses, enamels, &c. we must use a lamp, and make the stream of oxygen gas pass through its flame. For this purpose, we use the elbowed blow-pipe ST, instead of the bent one FG, employed with charcoal. The heat produced in this second manner, is by no means so intense as in the former way, and is very difficultly made to melt platina. In this manner of operating with the lamp, the substances are placed in cuppels of calcined bones, or little cups of porcelain, or even in metallic dishes. If these last be sufficiently large, they do not melt; because, metals being good conductors of heat, the caloric spreads rapidly through the whole mass, so that none of its parts are very much heated.

In the Memoirs of the Academy, for 1782, p. 476. and for 1783, p. 573. the series of experiments I have made with this apparatus may be seen at large. The following are some of the principal results.

1. Rock crystal, to pure silicious earth, is infusible, but becomes capable of being softened or fused when mixed with other substances.

2. Lime, magnesia, and barytes, are infusible, either when alone, or when combined together, but, especially lime; they assist the fusion of every other body.

3. Argill, or pure base of alum, is completely fusible *per se*, into a very hard, opaque, vitreous substance, which scratches glass like the precious stones.

4. All the compound earths and stones are readily fused into a brownish glass.

5. All the saline substances, even fixed alkali, are volatilized in a few seconds.

6. Gold, silver, and probably platina, are slowly volatilized without any particular phenomenon.

7. All other metallic substances, except mercury, become oxydated, though placed upon charcoal, and burn with different-coloured flames, and at last dissipate altogether.

8. The metallic oxyds likewise all burn with flames. This seems to form a distinctive character for these substances, and even leads me to believe, as was suspected by Bergman, that barytes is a metallic oxyd, though we have not hitherto been able to obtain the metal in its pure or reguline state.

9. Some of the precious stones, as rubies, are capable of being softened and soldered together, without injuring their colour, or even diminishing their weights. The hyacinth, though almost equally fixed with the ruby, loses its colour very readily. The Saxon and Brazilian topaz, and the Brazilian ruby, lose their colour very quickly, and lose about a fifth of their weight, leaving a white earth, resembling white quartz, or unglazed china. The emerald, chrysolite, and garnet, are almost instantly melted into an opaque and coloured glass.

10. The diamond presents a property peculiar to itself. It burns in the same manner with combustible bodies, and is entirely dissipated.

There is yet another manner of employing oxygen gas for considerably increasing the force of fire, by using it to blow a furnace. Mr A-chard first conceived this idea. But the process he employed, by which he thought to dephlogisticate, as it is called, atmospheric air, or to deprive it of azotic gas, is absolutely unsatisfactory. I propose to construct a very simple furnace, for this purpose, of very refractory earth, similar to the one represented Pl. XIII. Fig. 4. but smaller in all its dimensions. It is to have two openings, as at E, through one of which the nozzle of a pair of bellows is to pass, by which the heat is to be raised as high as possible with common air; after which, the



stream of common air from the bellows being suddenly stopt, oxygen gas is to be admitted through a tube, at the other opening, communicating with a gazometer having the pressure of four or five inches of water. I can in this manner unite the oxygen gas from several gazometers, so as to make eight or nine cubical feet of gas pass through the furnace ; and in this way I expect to produce a heat greatly more intense than any hitherto known. The upper orifice of the furnace must be carefully made of considerable dimensions, that the caloric produced may have free issue, lest the too sudden expansion of that highly elastic fluid should produce a dangerous explosion.

# A P P E N D I X.

## No. I.

*TABLE for Converting Lines, or Twelfth Parts of an Inch, and Fractions of Lines, into Decimal Fractions of the Inch.*

Twelfth Parts of a line.	Decimal Fractions.	Lines.	Decimal Fractions.
1	0.00694	1	0.08333
2	0.01389	2	0.16667
3	0.02083	3	0.25000
4	0.02778	4	0.33333
5	0.03472	5	0.41667
6	0.04167	6	0.50000
7	0.04861	7	0.58333
8	0.05556	8	0.66667
9	0.06250	9	0.75000
10	0.06944	10	0.83333
11	0.07639	11	0.91667
12	0.08333	12	1.00000

## No. II.

TABLE for Converting the Observed Heights of Water in the Jars of the Pneumato-Chemical Apparatus, expressed in Inches and Decimals, to Corresponding Heights of Mercury.

Water.	Mercury.	Water.	Mercury.
.1	.00737	4.	.29480
.2	.01474	5.	.36851
.3	.02211	6.	.44221
.4	.02948	7.	.51591
.5	.03685	8.	.58961
.6	.04422	9.	.66332
.7	.05159	10.	.73702
.8	.05896	11.	.81072
.9	.06633	12.	.88442
1.	.07370	13.	.96812
2.	.14740	14.	1.04182
3.	.22110	15.	1.11552

## No. III.

TABLE for Converting the Ounce Measures used by Dr. Priestley into French and English Cubical Inches\*.

Ounce measures.	French cubical inches.	English cubical inches.
1	1.567	1.898
2	3.134	3.796
3	4.701	5.694
4	6.268	7.592
5	7.835	9.490
6	9.402	11.388
7	10.969	13.286
8	12.536	15.184
9	14.103	17.082
10	15.670	18.980
20	31.340	37.960
30	47.010	56.940
40	62.680	75.920
50	78.350	94.900
60	94.020	113.880
70	109.690	132.860
80	125.360	151.840
90	141.030	170.820
100	156.700	189.800
1000	1567.000	1898.000

\* The ounce measure of Dr. Priestley contains an ounce troy, or 480 grains, of pure water. The Cubical contents,

## No. IV. ADDITIONAL.

*RULES for Reducing the Degrees of Reaumur's and of the Swedish Thermometer, to the Corresponding Degrees on Fahrenheit's Scale\*.*

The scale of Fahrenheit's thermometer is divided into 212 degrees, from Zero, the cold produced by a freezing mixture of salt and snow, to the temperature of boiling water.- Reaumur's scale has the Zero placed at the temperature of freezing water or melting ice; and the interval between that and the temperature of boiling water is divided into 80 degrees. The Swedish thermometer has its Zero in the same place with that of Reaumur; and the interval to the point of boiling water is divided into 109 degrees. These are the principal thermometers now used in Europe, and the temperature indicated by

as given in the above table, are retained from the French of Mr Lavoisier, reducing the French measure to English according to the best and most generally received comparison of their ratio, as given more at large in No. V. of this appendix. If, however, the experiments of Mr Everard be followed, as noticed in No. IX. of the appendix, the English cubical measure of one ounce ought to have been 1 8959, instead of the above.—T.

\* In the former edition of this translation, a table was given of the degrees on Reaumur's scale, with the corresponding degrees of Fahrenheit, from freezing to boiling water. But the formula in this article were thought more generally useful and more convenient.—T.

any of them may be reduced into the corresponding degrees on any of the others by means of the following simple canons; in which R signifies the degrees on the scale of Reaumur, F those of Fahrenheit, and S those of the Swedish thermometer.

1. To convert the degrees of Reaumur to those of Fahrenheit  $\frac{R \times 9}{4} + 32 = F.$

2. To convert the degrees of Fahrenheit to those of Reaumur;  $\frac{F - 32 \times 4}{9} = R.$

3. To convert the Swedish degrees to those of Fahrenheit;  $\frac{S \times 9}{5} + 32 = F.$

4. To convert Fahrenheit's to Swedish;  
 $\frac{F - 32 \times 5}{9} = S.$

5. To convert Swedish degrees to those of Reaumur;  $\frac{S \times 4}{5} = R.$

6. To convert Reaumur's degrees to Swedish;  
 $\frac{R \times 5}{4} = S.$

To such readers as are unacquainted with the algebraic expression of arithmetical formulæ, it will be sufficient to express one or two of these in words to explain their use.—1. Multiply the degree of Reaumur by 9, divide the product by 4, and to the quotient add 32, the sum expresses the degree on the scale of Fahrenheit.—

2. From the degree of Fahrenheit subtract 32,



multiply the remainder by 4, and divide the product by 9, the quotient is the degree according to the scale of Reaumur, &c.

# No. V. ADDITIONAL.

## RULES for Converting French Weights and Measures into correspondent English Denominations\*.

### § 1. Weights.

The Paris pound, poids de mark of Charlemagne, contains 9216 Paris grains. It is divided into 16 ounces, each ounce into 8 gros, and each gros into 72 grains. It is equal to 7561 English troy grains.

The English Troy pound, of 12 ounces, contains 5760 English Troy grains; and is equal to 7021 Paris grains.

The English averdupois pound of 16 ounces contains 7000 English Troy grains; and is equal to 8538 Paris grains.

To reduce Paris grs. to English Troy	}	1.2189
grs. divide by		
To reduce English Troy grs. to Paris		
grs. multiply by		

\* For the materials of this Article, the Translator is indebted to Professor Robinson.

To reduce Paris ounces to English }  
 Troy, divide by - - - } 1.015734  
 To reduce English Troy ounces to }  
 Paris, multiply by

Or the conversion may be made by means of  
 the following Tables.

I. *To reduce French to English Troy weight.*

The Paris pound	= 7561	} English Troy Grains.
The ounce	= 472.5625	
The gros	= 59.0703	
The Grain	= .8204	

II. *To reduce English Troy to Paris Weight.*

The English Troy pound	} = 7021.	} Paris grains.
of 12 ounces		
The Troy ounce	= 585.0833	
The dram of 60 grs.	= 73.1354	
The penny weight, or	} = 29.2541	
denier, of 24 grs.		
The scruple, of 20 grs.	= 24.3784	
The grain	= 1.2189	

III. *To reduce English Averdupois to Paris Weight.*

The averdupois pound of	} = 8538.	} Paris grains.
16 ounces, or 7000		
Troy grains,		
The ounce	= 533.6250	

§ 2. *Long and Cubical Measures*

To reduce Paris running feet or inches into English, multiply by	}	1.065977
English running feet or inches into Paris, divide by		
To reduce Paris cubic feet or inches to English, multiply by	}	1.211278
English cubic feet or inches to Paris divide by - - -		

Or by means of the following Tables :

IV. *To reduce Paris Long Measure to English.*

The Paris royal foot of	}	= 12.7977	} English inches.
12 inches			
The inch - - -	}	= 1.0659	
The line, or $\frac{1}{12}$ of an inch			
The $\frac{1}{12}$ of a line - -	}	= .0888	
The $\frac{1}{12}$ of a line - -			
The $\frac{1}{12}$ of a line - -	}	= .0074	
The $\frac{1}{12}$ of a line - -			

V. *To reduce English Long Measure to French.*

The English foot	= 11.2596	} Paris inches.
The inch -	= .9383	
The $\frac{1}{8}$ of an inch	= .1173	
The $\frac{1}{16}$ -	= .0938	
The line, or $\frac{1}{12}$	= .0782	

# VI. To Reduce French Cube Measure to English.

The Paris cube foot = 1.211278	}	English cubical feet, or	{	2093.688384	}	inches.
The cubic inch = .000700				1.211278		

# VII. To Reduce English Cube Measure to French\*.

The English cube foot, or 1728 cubical inches	} = 1427.4864 }	French cubical inches.	
The cubical inch			= .8260
The cube tenth			= .0008

## § 3. Measure of Capacity.

The Paris pint contains 58.145† English cubical inches, and the English wine pint contains

\* To convert the weight of a French cubic foot of any particular substance, given in French grains, into the corresponding weight of an English cubic Foot in English troy grains; multiply the French grains by 0.6773181, and the product is the number of English troy grains contained in an English cubic foot of the same substance.

† It is said by Belidor, *Archit. Hydrog.* to contain 31 oz. 64 grs. of water, which makes it 58.075 English inches. But, as there is considerable uncertainty in the

28.875\* cubical inches ; or, the Paris pint contains 2.0171082 English pints, and the English pint contains .49617 Paris pints ; hence,

To reduce the Paris pint to the	}	2.0171082
English, multiply by		
-		
To reduce the English pint to the		
Paris, divide by	-	-

The Septier of Paris is 7736 French, or 9370.45 English, cubical inches ; and the Muid is 92832 French, or 112445.4 English cubical inches.

determinations of the weight of the French cubical measure of water, owing to the uncertainty of the standards made use of, it is better to abide by Mr Everard's measure, which was made by the Exchequer standards, and by the proportion of the English and French foot, as established by the French Academy and Royal Society.

\* According to Beaumé, the Paris pint contains 32 French ounces of water, at the temperature of 54.5° of Fahrenheit ; which should make it equal to 59.729 English cubical inches.

## No. VI. ADDITIONAL.

*RULES for Reducing the Swedish Weights and Measures, used by the celebrated Bergman and Scheele, to English denominations\*.*

The Swedish pound, which is divided like the English Apothecary or Troy pound, weighs 6556 grs. troy.

The Kanne of pure water, according to Bergman, weighs 42250 Swedish grains, and occupies 100 Swedish cubical inches. Hence the Kanne of pure water weighs 48088.719444 English troy grains, or is equal to 189.9413 English cubic inches; and the Swedish longitudinal inch is equal to 1.238435 English longitudinal inches.

From these data, the following rules are deduced.

1. To reduce Swedish longitudinal inches to English—Multiply by 1.2384, or divide by 0.80747.
2. To reduce Swedish to English cubical inches—Multiply by 1.9, or divide by 0.5265.

\* For this article, which is added in the present edition, I am indebted to the friendly assistance of Dr. Rotheram.—T.



To reduce the Swedish pound, ounce, dram, scruple, or grain, to the corresponding English troy denomination, multiply by 1.382, or divide by .8786.

4. To reduce the Swedish Kannes to English wine pints, multiply by .1520207, or divide by 6.57804.

5. The Lod, a weight sometimes used by Bergman, is the 22d part of the Swedish pound : Therefore to reduce it to the English troy pound, multiply by .03557, or divide by 28.1156.

## No. VII.

TABLE of the Weights of the different Gasses, at 28 French inches, or 29.85 English inches barometrical pressure, and at  $54.5^{\circ}$  of temperature, expressed in English measure and English Troy weight.

Names of the Gasses.	Specific gravity, water being 1000	Weight of a cubical foot in grs.	Weight of a cubical inch in grs.
Atmospheric*	1.2308	538.45	.311023
Azotic	1.1890	520.17	.243154
Oxygen	1.3562	593.32	.343345
Hydrogen	0.094671	41.41	.023964
Carbonic acid	1.8454	807.34	.467326
†			
Nitrous	1.4631	640.09	.370422
Ammoniacal	0.73539	321.72	.186180
Sulphurous acid	1.8856	824.98	.471631

\* These five were ascertained by Mr Lavoisier himself.—T.

† The last three are inserted by Mr. Lavoisier, upon the authority of Mr Kirwan.—T.

## No. VIII.

## TABLES of the Specific Gravities of different Bodies.

§ 1. *Metallic Substances.*

## G O L D.

Pure gold, of 24 carats, melted but not hammered, - -	19.2581
The same hammered, -	19.3617
Gold of the Parisian standard, 22 carats fine, not hammered*,	17.4863
The same hammered, -	17.5894
Gold of the standard of French coin, 21 $\frac{2}{3}$ carats fine, not hammered,	17.4022
The same coined, - -	17.6474
Gold of the French trinket standard, 20 carats fine, not hammered,	15.7090
The same hammered,	15.7746

## S I L V E R.

Pure or virgin silver, 12 deniers, not hammered, - -	10.4743
The same hammered, -	10.5107
Silver of the Paris standard, 11 deniers 10 grains fine, not hammered†	10.1752
The same hammered, - -	10.3755

\* The same with Sterling.

† This is 10 grs. finer than Sterling.

Silver, standard of French coin, 10 deniers 21 grains fine, not hammered,	10.0476
The same coined,	10.4077

## P L A T I N A.

Crude platina in grains	15.6017
The same, after being treated with muriatic acid,	16.7521
Purified platina, not hammered,	19.5000
The same hammered,	20.3366
The same drawn into wire,	21.0417
The same passed through rollers,	22.0690

## C O P P E R   A N D   B R A S S.

Copper not hammered,	7.7880
The same wire drawn,	8.8785
Brass not hammered,	8.3958
The same wire drawn,	8.5441
Common cast brass,	7.8240

## I R O N   A N D   S T E E L.

Cast iron,	7.2070
Bar iron, either hardened or not,	7.7880
Steel, neither tempered nor hardened,	7.8331
Steel hardened under the hammer, but not tempered.	7.8404
Steel tempered and hardened,	7.8180
Steel, tempered and not hardened,	7.8163

## O T H E R M E T A L S.

Pure tin from Cornwall, melted and not

hardened,	-	-	7.2914
The same hardened,	-	-	7.2994
Malacca tin, not hardened,	-	-	7.2963
The same hardened,	-	-	7.3065
Molten lead	-	-	11.3523
Molten zinc	-	-	7.1908
Molten bismuth,	-	-	9.8227
Molten cobalt,	-	-	8.8119
Molten arsenic,	-	-	5.7633
Molten nickel,	-	-	7.8070
Molten antimony,	-	-	6.7021
Crude antimony,	-	-	4.0643
Glass of antimony,	-	-	4.9464
Molybdena	-	-	4.7385
Tungstein,	-	-	6.0665
Mercury	-	-	13.5681
Uranium,	-	-	6.4400

§ 2. *Precious Stones.*

White Oriental diamond,	-	-	3.5212
Rose-coloured Oriental ditto,	-	-	3.5310
Oriental ruby,	-	-	4.2833
Spinell ditto,	-	-	3.7600
Ballas ditto,	-	-	3.6458
Brazilian ditto,	-	-	3.5311
Oriental topaz,	-	-	4.0106

Oriental Pistachio topaz	-	-	4.0615
Brazilian ditto	-	-	3.5365
Saxon ditto	-	-	3.5640
Ditto white ditto	-	-	3.5535
Oriental Saphir	-	-	3.9911
Ditto white ditto	-	-	3.9911
Saphir of Puy	-	-	4.0769
Ditto of Brasil	-	-	3.1307
Girafol	-	-	4.0000
Ceylon jargon	-	-	4.4161
Hyacinth	-	-	3.6873
Vermillion	-	-	4.2299
Bohemian garnet	-	-	4.1883
Dodecahedral ditto	-	-	4.0627
Syrian ditto	-	-	4.0000
Volcanic ditto with 24 fides	-	-	2.4684
Peruvian emerald	-	-	2.7755
Chrysolite of the jewellers	-	-	2.7821
Ditto of Brasil	-	-	2.6923
Beryl, or Oriental aqua marine	-	-	3.5489
Occidental aqua marine	-	-	2.7227

### § 3. *Silicious Stones.*

Pure rock crystal of Madagascar	-	-	2.6530
Ditto of Brasil	-	-	2.6526
Ditto of Europe, or gelatinous	-	-	2.6548
Crystallized quartz	-	-	2.6546
Amorphous ditto	-	-	2.6471
Oriental agate	-	-	2.5901



Agate onyx	-	-	2.6375
Transparent calcedony	-	-	2.6640
Cornelian	-	-	2.6137
Sardonyx	-	-	2.6025
Prase	-	,	2.5805
Onyx pebble	-	-	2.6644
Pebble of Rennes	-	-	2.6538
White jade	-	-	2.9502
Green jade	-	-	2.9660
Red jasper	-	-	2.6612
Brown ditto	-	-	2.6911
Yellow ditto	-	-	2.7101
Violet ditto	-	-	2.7111
Grey ditto	-	-	2.7640
Jasponyx	-	-	2.8160
Black prismatic hexahedral schorl			3.3852
Black sparry ditto	-	-	3.3852
Black amorphous schorl, called antique			
basaltes	-	-	2.9225
Paving stone	-	-	2.4158
Grind stone	-	-	2.1429
Cutler's stone	-	-	2.1113
Fountainbleau stone	-	-	2.5616
Scythe stone of Auvergne		-	2.5638
Ditto of Lorrain	-	-	2.5298
Mill stone	-	-	2.4835
White flint	-	-	2.5941
Blackish ditto	-	-	2.5817

§ 4. *Various Stones, &c.*

Opake green Italian serpentine, or gabro			
of the Florentines	-	-	2.4295
Coarse Briançon chalk	-	-	2.7274
Spanish chalk	-	-	2.7902
Foliated lapis ollaris of Dauphiny			2.7687
Ditto ditto from Sweden	-		2.8531
Muscovy talc	-	-	2.7917
Black mica	-	-	2.9004
Common schistus or slate		-	2.6718
New slate	-	-	2.8535
White rasor hone	-	-	2.8763
Black and white hone	-	-	3.1311
Rhombic or Iceland crystal		-	2.7151
Pyramidal calcareous spar	-	-	2.7302
Oriental or white antique alabaſter			2.7141
Green Campan marble		-	2.7417
Red Campan marble	-	-	2.7242
White Carara marble	-	-	2.7168
White Parian marble	-	-	2.8376
Various kinds of calcareous ſtones	} from		1.3864
uſed in France for building		} to	2.3902
Ore of Uranium	-	-	7.5000
Heavy ſpar	-	-	4.4300
Strontitic ſpar	-	-	{ 3.7260
			{ 3.6500
White fluor	-	-	3.1555
Red ditto	-	-	3.1911
Green ditto	-	-	3.1817
Blue ditto	-	-	3.1622

Violet fluor	-	-	-	3.1757
Red Scintilant zeolite from Edelfors				2.4868
White scintilant zeolite			-	2.0739
Crytallized zeolite	-	-	.	2.0833
Black pitch stone	-	-		2.0499
Yellow pitch stone	-	-	-	1.0860
Red ditto	-		-	2.6695
Blackish ditto	-	-	-	2.3191
Red Porphyry	-		-	2.7651
Ditto of Dauphiny		-	-	2.7033
Green serpentine	-		-	2.8960
Black ditto of Dauphiny, called variolite				2.9339
Green ditto from Dauphiny	-		-	2.9883
Ophites	-	-		2.9722
Granitello	-		-	3.0626
Red Egyptian granite	-		-	2.6541
Beautiful red granite		-	-	2.7609
Granite of Girardmas		-	-	2.7163
Pumice stone	-		-	.9145
Lapis obsidianus	-		-	2.3480
Pierre de Volvic	-	-	-	2.3205
Touch stone	-	-	-	2.4153
Basaltcs from Giants' Causeway			-	2.8642
Ditto prismatic from Auvergne			-	2.4153
Glass gall	-		-	2.8548
Bottle glass	-		-	2.7325
Green glass	-		-	2.6423
White glass	-		-	2.8922
St. Gobin crystal	-		-	2.4882
Leith crystal	-	-	-	3.1890

Flint glafs	-	-	3.3293
Borax glafs	-	-	2.6070
Seves porcelain	-	-	2.1457
Limoges ditto,	-	-	2.3410
China ditto	-	-	2.3847
Native fulphur	-	-	2.0332
Melted fulphur	-	-	1.9907
Phosphorus	-	-	1.7140
Hard peat	-	-	1.3290
Ambergreafe	-	-	.9263
Yellow transparent amber	-	-	1.0780

§ 5. *Liquids.*

Distilled water	-	-	1.0000
Rain water	-	-	1.0000
Filtered water of the Seine	-	-	1.00015
Arcueil water	-	-	1.00046
Avray water	-	-	1.00043
Sea water	-	-	1.0263
Water of the Dead Sea	-	-	1.2403
Burgundy wine	-	-	.9915
Bordeaux ditto	-	-	.9939
Malmsey Madeira	-	-	1.0382
Red-beer	-	-	1.0338
White ditto	-	-	1.0231
Cyder	-	-	1.0181
Highly rectified alkohol	-	-	.8293
Common spirits of wine	-	-	.8371

Alkohol	15 pts. water	1 part.	.8527
	14	2	.8674
	13	3	.8815
	12	4	.8947
	11	5	.9075
	10	6	.9199
	9	7	.9317
	8	8	.9427
	7	9	.9519
	6	10	.9594
	5	11	.9674
	4	12	.9733
	3	13	.9791
	2	14	.9852
	1	15	.9919
Sulphuric ether	-	-	.7394
Nitric ether	-	-	.9088
Muriatic ether	-	-	.7298
Acetic ether	-	-	.8664
Highly concentrated Sulphuric acid			2.1250
Common Sulphuric acid			1.8409
Highly concentrated Nitric acid			1.5800
Common Nitric ditto		-	1.2715
Muriatic ditto	-	-	1.1940
Fluoric acid	-	-	1.5000
Red acetous ditto	-	-	1.0251
White acetous ditto	-	-	1.0135
Distilled ditto ditto	-	-	1.0095

Acetic acid	-	-	1.0626
Formic ditto	-	-	.9942
Solution of caustic ammoniac, or volatile alkali fluor	-	-	.8970
Essential or volatile oil of turpentine			.8697
Liquid turpentine	-	-	.9910
Volatile oil of lavender		-	.8938
Volatile oil of cloves	-	-	1.0363
Volatile oil of cinnamon		-	1.0439
Oil of olives	-	-	.9153
Oil of sweet almonds	-	-	.9170
Lintseed oil	-	-	.9403
Oil of poppy seed	-	-	.9288
Oil of beech mast	-	-	.9176
Whale oil	-	-	.9233
Woman's milk	-	-	1.0203
Mare's milk	-	-	1.0346
Ass's milk	-	-	1.0355
Goat's milk	-	-	1.0341
Ewe milk	-	-	1.0409
Cow's milk	-	-	1.0324
Cow whey	-	-	1.0193
Human urine	-	-	1.0106

### § 6. *Resins and Gums.*

Common yellow or white resin		1.0727
Arcanfon	-	1.0857



Galipot*	-	-	1.0819
Baras*	-	-	1.0441
Sandarac	-	-	1.0920
Mastic	-	-	1.0742
Storax	-	-	1.1098
Opaque copal	-	-	1.1398
Transparent ditto	-	-	1.0452
Madagascar ditto	-	-	1.0600
Chinefe ditto	-	-	1.0628
Elemi	-	-	1.0182
Oriental anime	-	-	1.0284
Occidental ditto	-	-	1.0426
Labdanum	-	-	1.1862
Ditto <i>in tortis</i>	-	-	2.4933
Resin of guaiac	-	-	1.2289
Ditto of jallap	-	-	1.2185
Dragons blood	-	-	1.2045
Gum lac	-	-	1.1390
Tacamahaca	-	-	1.0463
Benzoin	-	-	1.0924
Alouchit†	-	-	1.0604
Caragna‡	-	-	1.1244
Elastic gum	-	-	.9335
Camphor	-	-	.9887
Gum ammoniac	-	-	1.2071
Sagapenum	-	-	1.2008

\* Resinous juices extracted in France from the Pine.  
*Vide Bomare's Dict.*

† Odoriferous gum from the tree which produces the Cortex Winteranus. *Ibid.*

‡ Resin of the tree called in Mexico Caragna, or Tree of Madness. *Ibid.*

Ivy gum*	-	-	1.2948
Gamboge	-	-	1.2216
Euphorbium	-	-	1.1244
Olibanum	-	-	1.1732
Myrrh	-	-	1.3600
Bdellium	-	-	1.3717
Aleppo Scamony	-	-	1.2354
Smyrna ditto	-	-	1.2743
Galbanum	-	-	1.2120
Affafoetida	-	-	1.3275
Sarcocolla	-	-	1.2684
Opoponax	-	-	1.6226
Cherry-tree gum	-	-	1.4817
Gum Arabic	-	-	1.4523
Tragacanth	-	-	1.3161
Baffora gum	-	-	1.4346
Acajou gum†	-	-	1.4456
Monbain gum‡	-	-	1.4206
Inspissated juice of liquorice	-	-	1.7228
————— Acacia	-	-	1.5153
————— Areca	-	-	1.4573
Terra Japonica	-	-	1.3980
Hepatic aloes	-	-	1.3586
Socotrine aloes	-	-	1.3795
Inspissated juice of St John's wort	-	-	1.5263

\* Extracted in Persia and the warm countries from *Hedera terrestris*.—*Bonare*.

† From a Brazilian tree of this name. *Ibid*.

‡ From a tree of this name.—*Ibid*.

Opium	-	-	1.3366
Indigo	-	-	.7690
Arnotto	-	-	.5956
Yellow wax	-	-	.9648
White ditto	-	-	.9686
Ouarouchi ditto*	-	-	.8970
Cacao butter	-	-	.8916
Spermaceti	-	-	.9433
Beef fat	-	-	.9232
Veal fat	-	-	.9342
Mutton fat	-	-	.9235
Tallow	-	-	.9419
Hogs fat	-	-	.9368
Lard	-	-	.9478
Butter	-	-	.9423

§ 7. *Woods.*

Heart of oak 60 years old	-	1.1700
Cork	-	.2400
Elm trunk	-	.6710
Ash ditto	-	.8450
Beech	-	.8520
Alder	-	.8000
Maple	-	.7550
Walnut	-	.6710
Willow	-	.5850
Linden	-	.6040

\* The produce of the Tallow Tree of Guiana. *Vide Bonmare's dict.*

Male fir	-	-	-	.5500
Female ditto	-	-	-	.4980
Poplar	-	-	-	.3830
White Spanish ditto	-	-	-	.5294
Apple tree	-	-	-	.7930
Pear tree	-	-	-	.6610
Quince tree	-	-	-	.7050
Medlar	-	-	-	.9440
Plumb tree	-	-	-	.7850
Olive wood	-	-	-	.9270
Cherry tree	-	-	-	.7150
Filbert tree	-	-	-	.6000
French box	-	-	-	.9120
Dutch ditto	-	-	-	1.3280
Dutch yew	-	-	-	.7880
Spanish ditto	-	-	-	.8070
Spanish cypress	-	-	-	.6440
American cedar	-	-	-	.5608
Pomegranate tree	-	-	-	1.3540
Spanish mulberry tree	-	-	-	.8970
Lignum vitæ	-	-	-	1.3330
Orange tree	-	-	-	.7050

*Note*—The numbers in the above Table, if the Decimal point be carried three figures farther to the right hand, nearly express the absolute weight of an English cube foot of each substance in averdupois ounces. See No. IX. of the Appendix. — T.

## No. IX. ADDITIONAL.

*RULES for Calculating the Absolute Gravity in English Troy Weight of a Cubic Foot and Inch, English Measure, of any Substance whose Specific Gravity is known\*.*

In 1696, Mr Everard, balance-maker to the Exchequer, weighed before the Commissioners of the House of Commons 2145.6 cubical inches, by the Exchequer standard foot, of distilled water, at the temperature of  $55^{\circ}$  of Fahrenheit; and found it to weigh 1131 oz. 14 dts. Troy, of the Exchequer standard. The beam turned with 6 grs. when loaded with 30 pounds in each scale. Hence, supposing the pound averdupois to weigh 7000 grs. Troy, a cubic foot of water weighs  $62\frac{1}{2}$  pounds averdupois or 1000 ounces averdupois, wanting 106 grains Troy. And hence, if the specific gravity of water be called 1000, the proportional specific gravities of all other bodies will nearly express the number of averdupois ounces in a cubic foot. Or, more accurately, supposing the specific gravity of water expressed by 1. and of all other bodies in proportional numbers, as the

\* The whole of this and the following article was communicated to the Translator by Professor Robinson——T.

cubic foot of water weighs, at the above temperature, exactly 437489.4 grains Troy, and the cubic inch of water 253.175 grains, the absolute weight of a cubical foot or inch of any body in Troy grains, may be found by multiplying their specific gravity by either of the above numbers respectively.

By Everard's experiment, and the proportions of the English and French Foot, as established by the Royal Society and French Academy of Sciences, the following numbers are ascertained.

Paris grains in a Paris cube foot of			
water	-	-	=645511
English grains in a Paris cube foot			
of water	-	-	=529922
Paris grains in an English cube foot			
of water	-	-	=533247
English grains in an English cube			
foot of water	-	-	=437489.4
English grains in an English cube			
inch of water	-	-	=253.175
By an experiment of Picard with			
the measure and weight of the			
Chatelet, the Paris cube foot of			
water contains of Paris grains			=641326
By one of Du Hamel, made with			
great care	-	-	=641376
By Homberg	-	-	=641666



These shew some uncertainty in measure or in weights; but the above computation from Everard's experiment may be relied on, because the comparison of the foot of England with that of France was made by the joint labour of the Royal Society of London and the French Academy of Sciences. It agrees likewise very nearly with the weight assigned by Mr Lavoisier, 70 Paris pounds to the cubical foot of water.

No. X.

TABLES for Converting Ounces, Drams, and Grains, Troy, into Decimals of the Troy Pound of 12 Ounces, and for Converting Decimals of the Pound Troy into Ounces, &c.

I. For Grains.

Grains = Pound.		Grains = Pound.	
1	.0001736	100	.0173611
2	.0003472	200	.0347222
3	.0005208	300	.0520833
4	.0006944	400	.0694444
5	.0008681	500	.0868055
6	.0010417	600	.1041666
7	.0012153	700	.1215277
8	.0013889	800	.1388888
9	.0015625	900	.1562499
10	.0017361	1000	.1736110
<hr/>		<hr/>	
20	.0034722	2000	.3472220
30	.0052083	3000	.5208330
40	.0069444	4000	.6944440
50	.0086806	5000	.8680550
60	.0104167	6000	1.0416660
70	.0121528	7000	1.2152770
80	.0138889	8000	1.3888880
90	.0156250	9000	1.5624990

II. *For Drams.*

Drams = Pound.

1	.0104167
2	.0208333
3	.0312500
4	.0416667
5	.0520833
6	.0625000
7	.0729167
8	.0833333

III. *For Ounces.*

Ounces = Pounds.

1	.0833333
2	.1666667
3	.2500000
4	.3333333
5	.4166667
6	.5000000
7	.5833333
8	.6666667
9	.7500000
10	.8333333
11	.9166667
12	1.0000000

IV. *Decimals of the Pound into Ounces, &c.*

<i>Tenth parts.</i>				<i>Thousandths.</i>	
<i>lib. =</i>	<i>oz.</i>	<i>dr.</i>	<i>gr.</i>	<i>lib. =</i>	<i>grs.</i>
0.1	1	1	36	0.006	34.56
0.2	2	3	12	0.007	40.32
0.3	3	4	48	0.008	46.08
0.4	4	6	24	0.009	51.84
0.5	6	0	0	<i>Ten thousandth parts.</i>	
0.6	7	1	36	0.0001	0.576
0.7	8	3	12	0.0002	1.152
0.8	9	4	48	0.0003	1.728
0.9	10	6	24	0.0004	2.304
<i>Hundredth parts.</i>				0.0005	2.880
0.01	0	0	57.6	0.0006	3.456
0.02	0	1	55.2	0.0007	4.032
0.03	0	2	52.8	0.0008	4.608
0.04	0	3	50.4	0.0009	5.184
0.05	0	4	48.0	<i>Hundred thousandth parts.</i>	
0.06	0	5	45.6	0.00001	0.057
0.07	0	6	43.2	0.00002	0.115
0.08	0	7	40.8	0.00003	0.173
0.09	0	8	38.4	0.00004	0.230
<i>Thousandths.</i>				0.00005	0.288
0.001	0	0	5.76	0.00006	0.346
0.002	0	0	11.52	0.00007	0.403
0.003	0	0	17.28	0.00008	0.461
0.004	0	0	23.04	0.00009	0.518
0.005	0	0	28.80		

## No. XI.

TABLE of the English Cubical Inches and Decimals corresponding to a determinate Troy weight of distilled Water of the Temperature of  $55^{\circ}$ , calculated from Everard's experiment.

<i>For Grains.</i>		<i>For Ounces.</i>	
Grs.	Cubical Inches.	Oz.	Cubical Inches.
1 =	.0039	1 =	1.8959
2	.0079	2	3.7918
3	.0118	3	5.6877
4	.0158	4	7.5837
5	.0197	5	9.4796
6	.0237	6	11.3755
7	.0276	7	13.2714
8	.0316	8	15.1674
9	.0355	9	17.0633
10	.0395	10	18.9592
20	.0790	11	20.8551
30	.1185		
40	.1580		
50	.1974		
<i>For Drams.</i>		<i>For Pounds</i>	
Drams	Cubical Inches.	Libs.	Cubical Inches.
1 =	.2370	1 =	22.7510
2	.4739	2	45.5021
3	.7109	3	68.2531
4	.9479	4	91.0042
5	1.1849	5	113.7553
6	1.4219	6	136.5063
7	1.6589	7	159.2574
		8	182.0084
		9	204.7595
		10	227.5106
		50	1137.5530
		100	2275.1061
		1000	22751.0615

## No. XII. ADDITIONAL.

TABLE of the Comparative Heats of different Bodies,  
as ascertained by Crawford.

Hydrogen gas	-	-	-	21.4000
Oxygen gas	-	-	-	4.7490
Atmospheric air	-	-	-	1.7900
Steam or aqueous vapour	-	-	-	1.5500
Carbonic acid gas	-	-	-	1.0454
Arterial blood	-	-	-	1.0300
Water	-	-	-	1.0000
Cow's milk	-	-	-	.9999
Venous blood	-	-	-	.8928
Azotic gas	-	-	-	.7936
Hide of an ox with the hair	-	-	-	.7870
Lungs of a sheep	-	-	-	.7690
Muscular flesh of an ox	-	-	-	.7400
Alcohol	-	-	-	.6021
Rice	-	-	-	.5060
Horse beans	-	-	-	.5020
Spermaceti oil	-	-	-	.5000
Fruit of the pine tree	-	-	-	.5000
Pease	-	-	-	.4920
Wheat	-	-	-	.4770
Barley	-	-	-	.4210
Oats	-	-	-	.4160
Sulphuric acid	-	-	-	.4290
Pitcoal	-	-	-	.2771
Charcoal	-	-	-	.2631
Chalk	-	-	-	.2564
Rust of iron	-	-	-	.2500
Washed diaphoretic Antimony	-	-	-	.2272
Oxyd of Copper nearly freed from air	-	-	-	.2272
Quicklime	-	-	-	.2229
Cinders	-	-	-	.1923
Ashes of Pitcoal	-	-	-	.1855
Rust of iron nearly freed from air	-	-	-	.1666
Washed diaphoretic Antimony Do.	-	-	-	.1666
Ashes of elm wood	-	-	-	.1402
Oxyd of Zinc nearly freed from air	-	-	-	.1369
Iron	-	-	-	.1269
Brass	-	-	-	.1123



Copper	-	-	-	.1111
White oxyd of tin almost free of air	-	-	-	.0990
Zinc	-	-	-	.0943
Ashes of charcoal	-	-	-	.0909
Tin	-	-	-	.0704
Yellow oxyd of lead almost free of air	-	-	-	.0680
Antimony	-	-	-	.0645
Lead	-	-	-	.0352

## No. XIII. ADDITIONAL.

TABLE of the Ingredients in Neutral Salts, as determined by Kirwan.

	Acid	Alk.	Water
Sulphuric potash	31	63	6
Sulphuric soda	14	22	64
Sulphurac ammoniac	42	40	18
Nitric potash	30	63	7
Nitric soda	29	50	21
Nitric ammoniac	46	40	14
Muriatic potash	30	63	7
Muriatic soda	33	50	17
Muriatic ammoniac	52	40	8
Boracic soda	34	17	47

*Earthy Salts.*

	Acid	Earth	Water
Sulphuric magnesia	24	19	57
Sulphuric argill	24	18	58
Nitric calx	33	32	35
Nitric magnesia	36	27	37
Carbonic frontites	30	61	9

*Metallic Salts.*

	Acid	Metal	Water
Sulphuric Iron	20	25	55
Do. Copper	30	27	43
Do. Zinc	22	20	58

F I N I S.

Fig. 3.



Fig. 2.



Fig. 1.



Fig. 5.



Fig. 4.

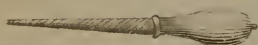


Fig. 13.



Fig. 12.

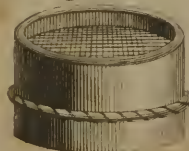


Fig. 15.



Fig. 14.



Fig. 11.



Fig. 9.



Fig. 6.



Fig. 7.

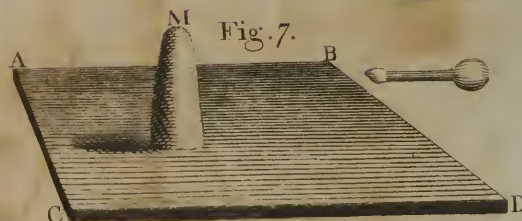
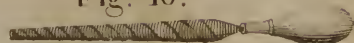


Fig. 8.



Fig. 10.



Sold by M. CAREY N<sup>o</sup> 118 Market St PHILADA.



Fig. 1.



Fig. 2.

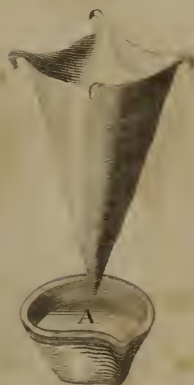


Fig. 5.



Fig. 7.



Fig. 6.



Fig. 8.

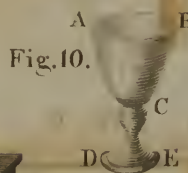


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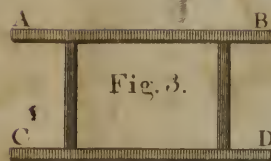


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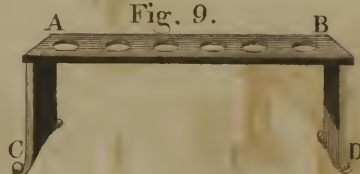


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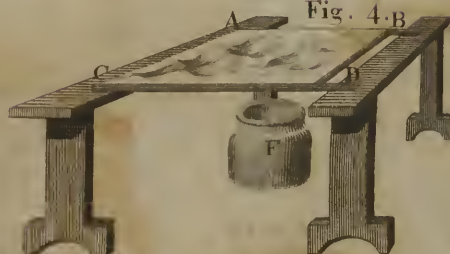


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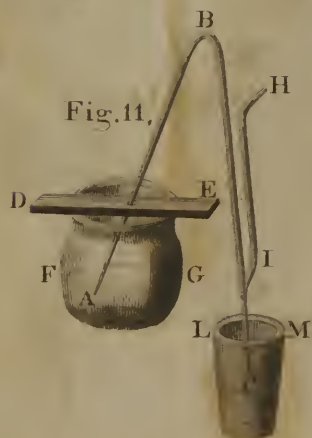


Fig. 12.



Fig. 13.

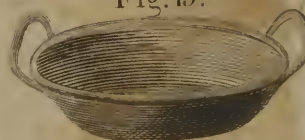


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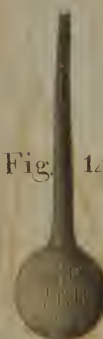


Fig. 15.



Fig. 16.



Fig. 17.







Plate III.

Fig. 1.

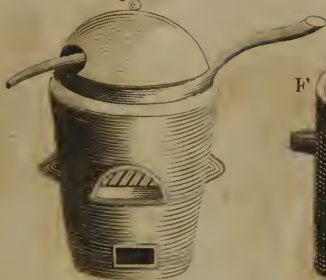


Fig. 2.



Fig. 3.



Fig. 4.



Fig. 5.



Fig. 6.



Fig. 14.

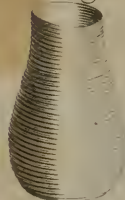


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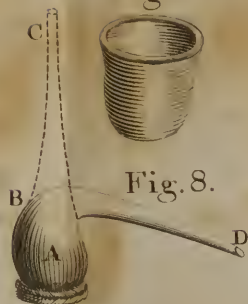


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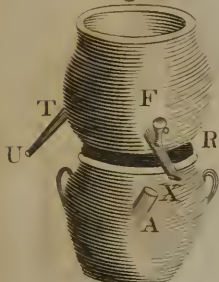


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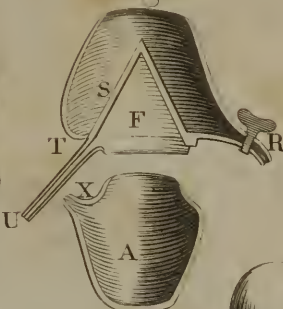


Fig. 7.



Fig. 9.

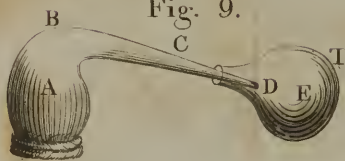


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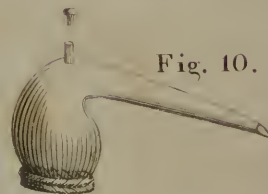


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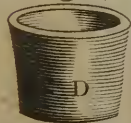


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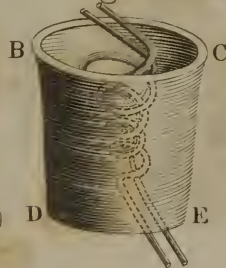


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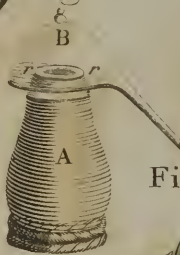


Fig. 13.



Fig. 24.

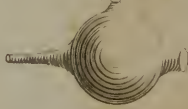


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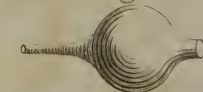


Fig. 22.



Fig. 20.

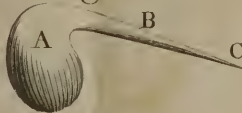


Fig. 21.



Fig. 19.







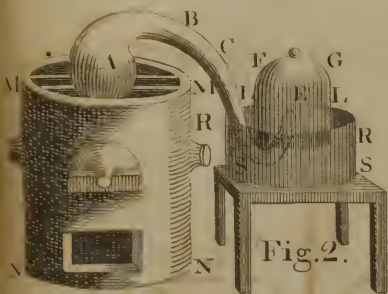


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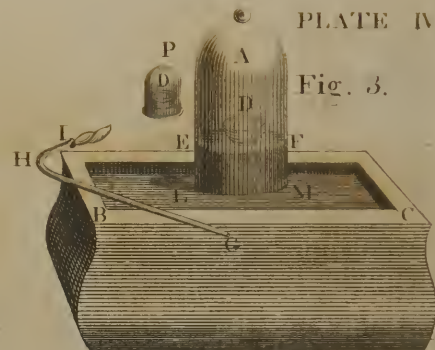


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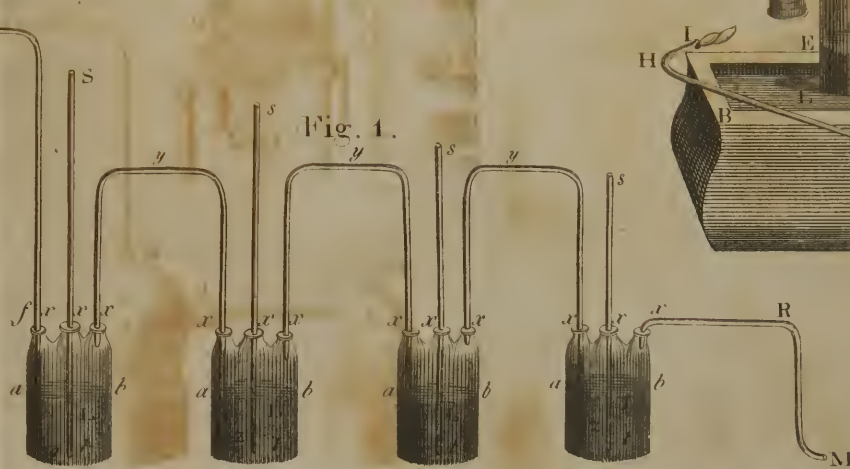
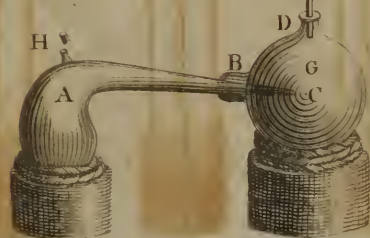


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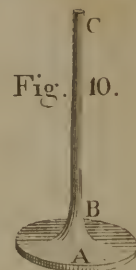


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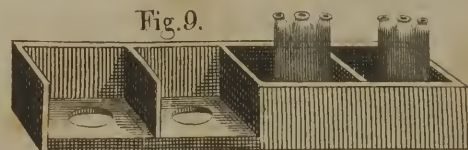


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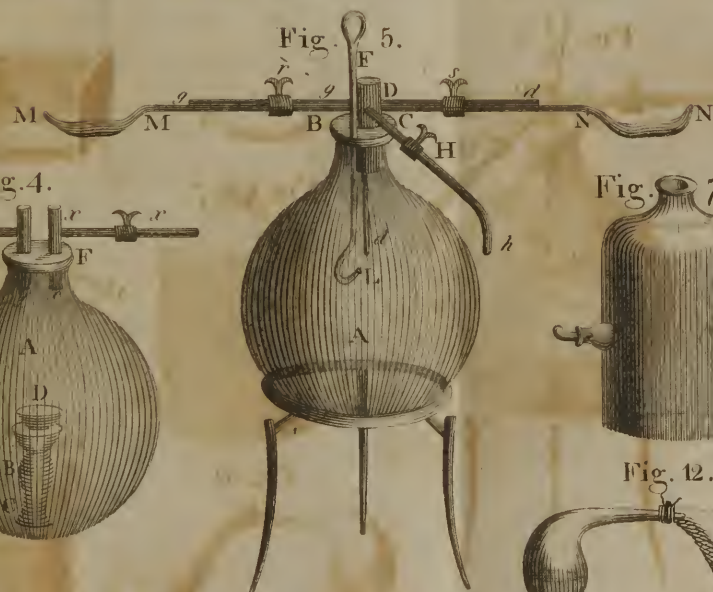


Fig. 5.



Fig. 16.

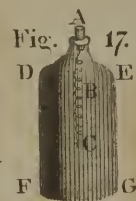


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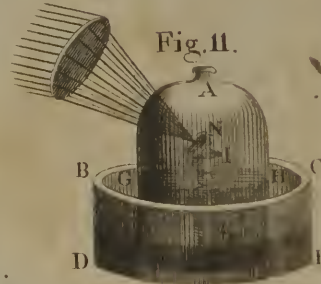


Fig. 11.



Fig. 12.



Fig. 13.



Fig. 14.



Fig. 15.



Fig. 6.



Fig. 8.





Fig. 1.



Fig. 2.

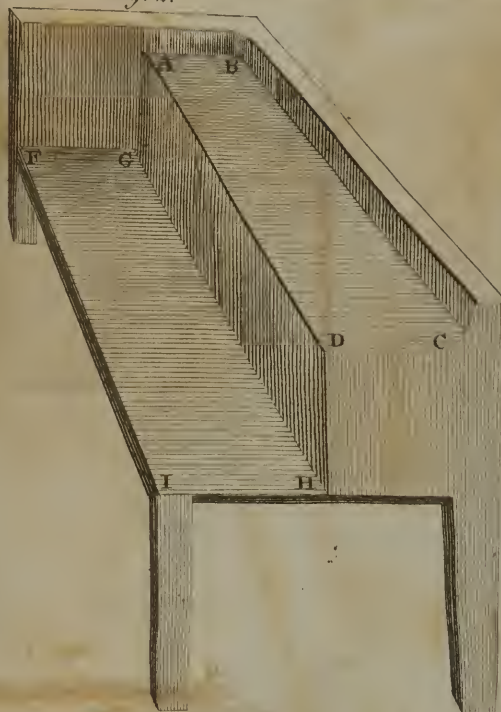


Fig. 8.



Fig. 9.

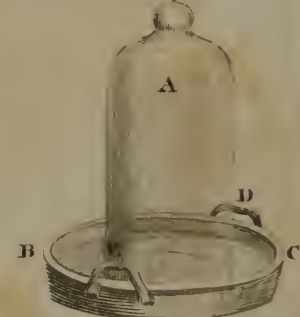


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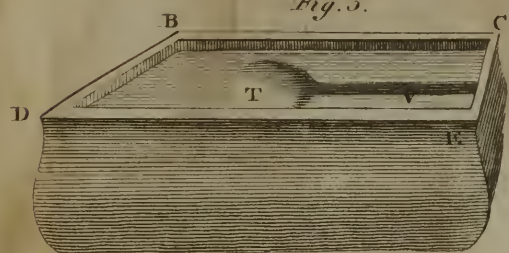


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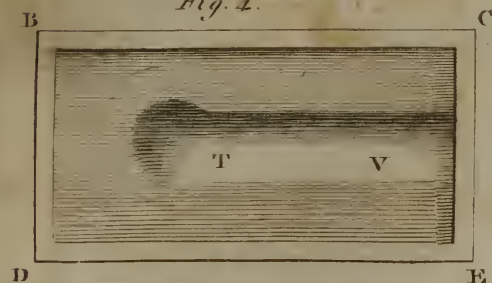


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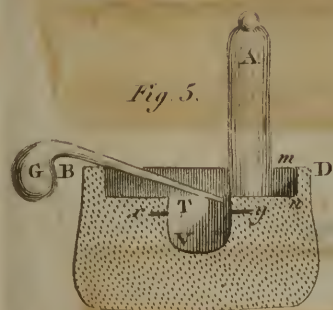


Fig. 6.



Fig. 11.



Fig. 12.



Fig. 7.



Fig. 13.

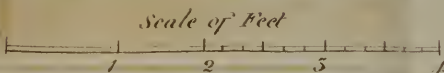
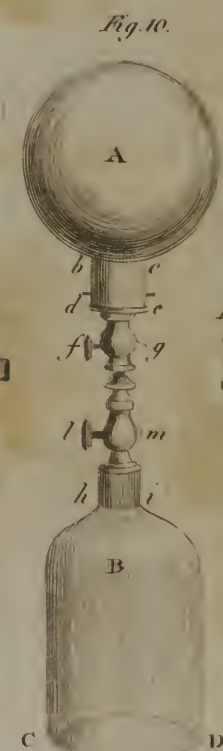




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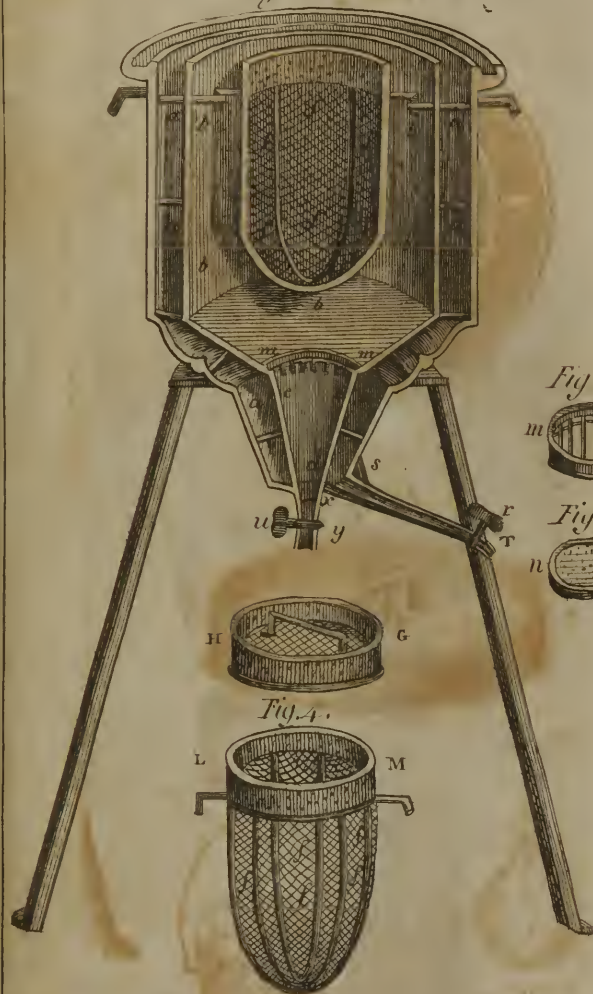


Fig. 2.



Fig. 5.



Fig. 6.



Fig. 7.

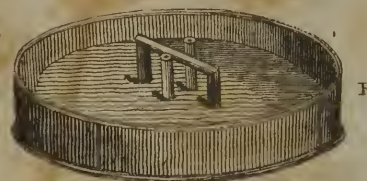


Fig. 9.



Fig. 8.



Fig. 10.



Scale of Feet.

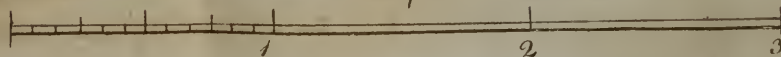


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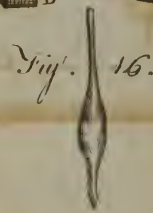
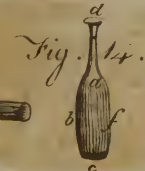
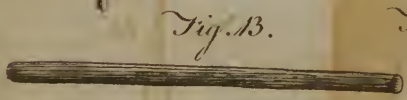
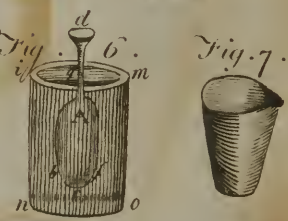
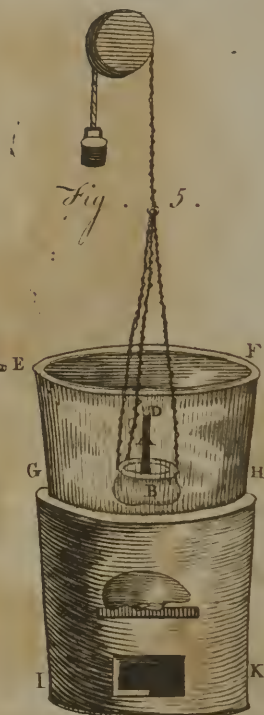
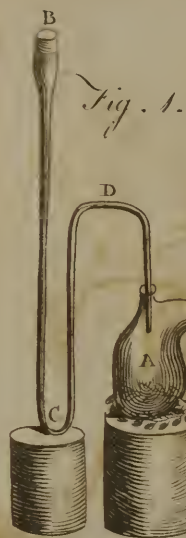






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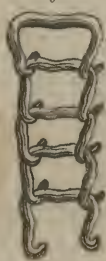


Fig. 4.



Fig. 5.

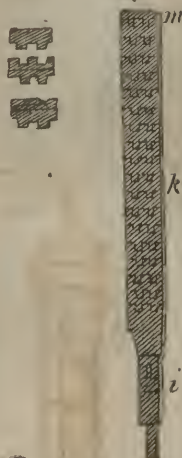


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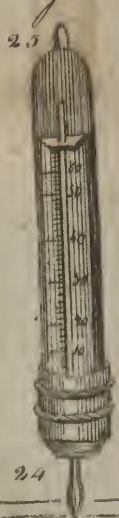


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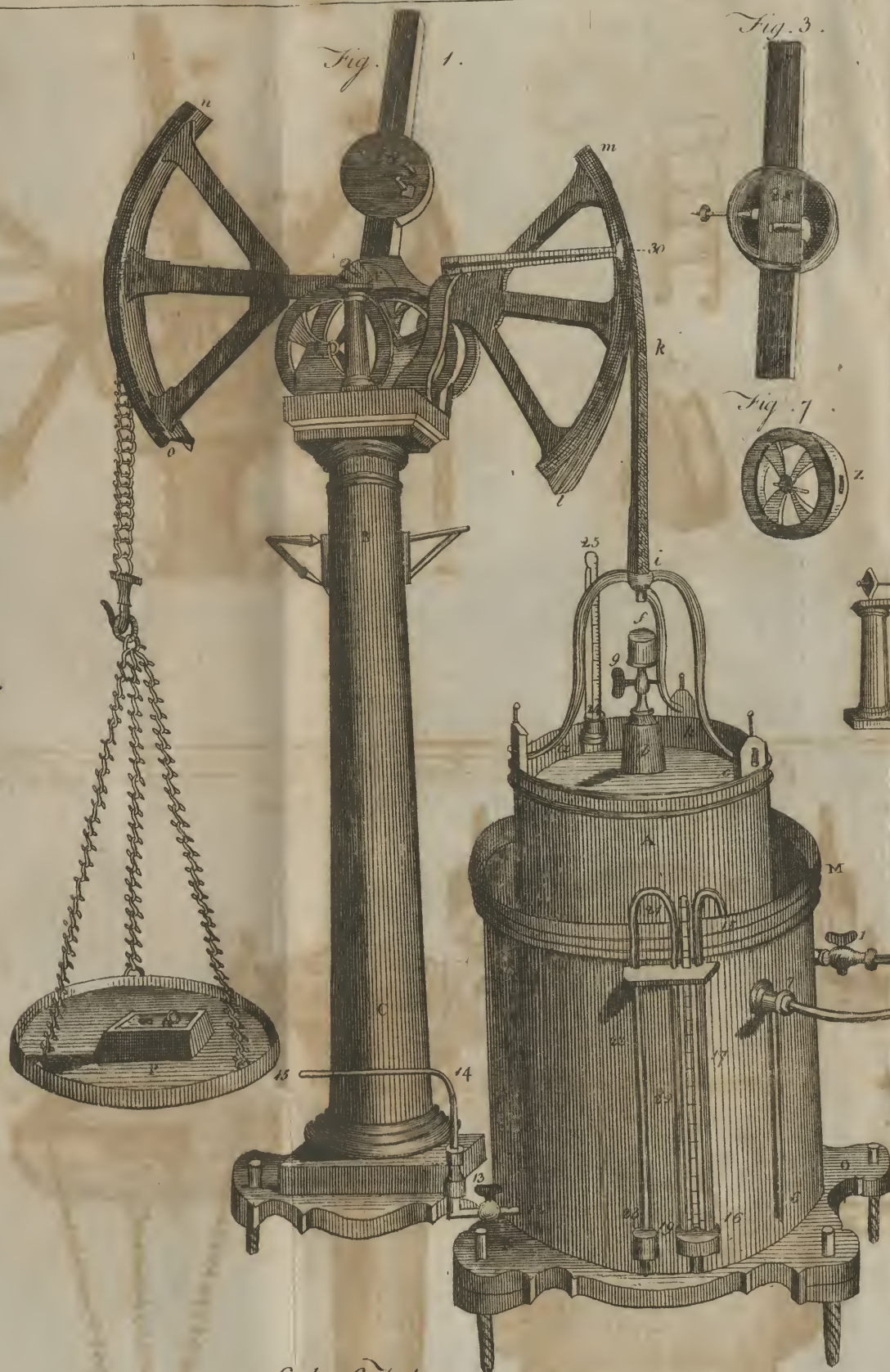


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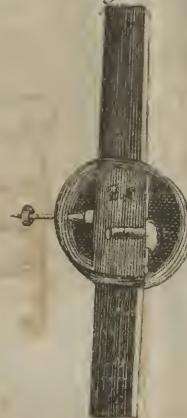


Fig. 7.



Fig. 6.

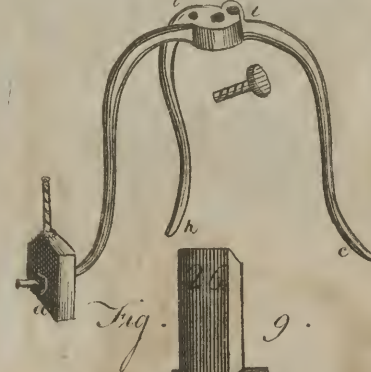


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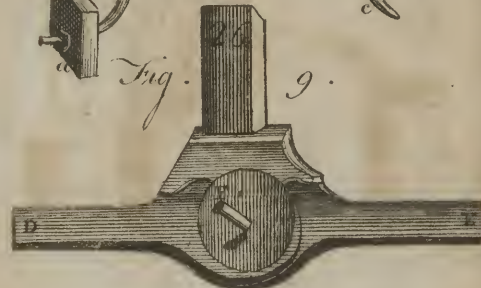
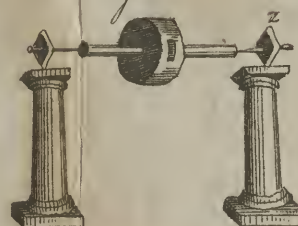


Fig. 8.



Scale of Feet.

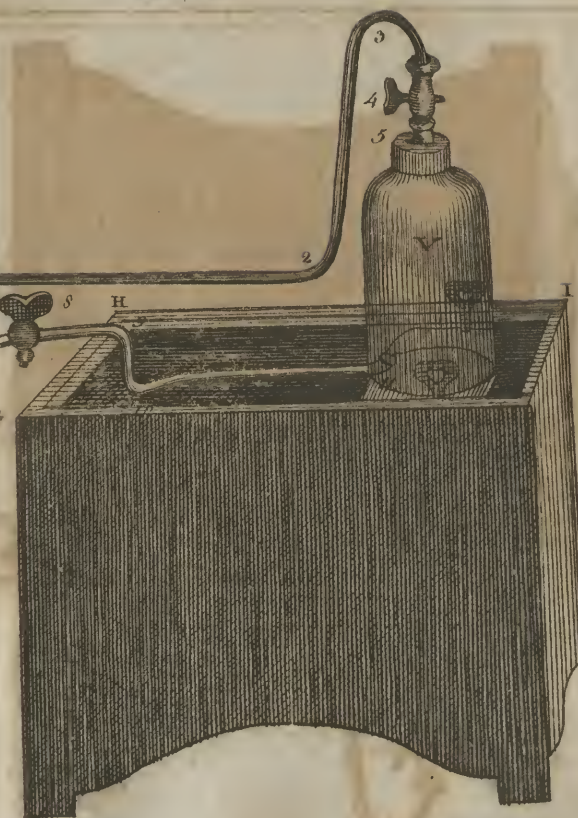
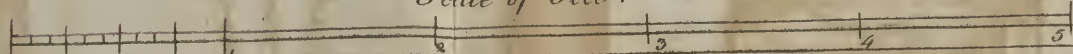






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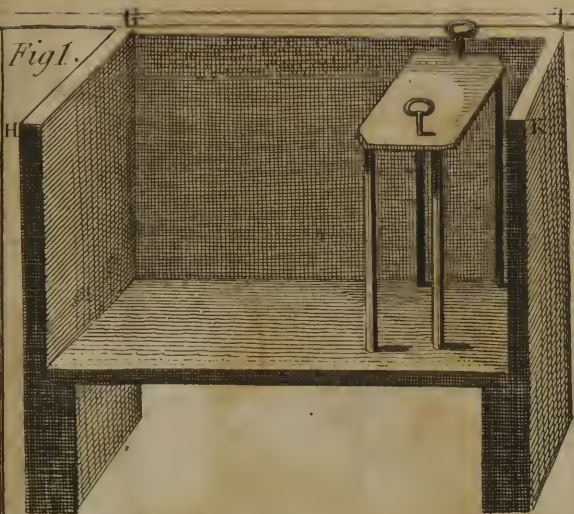
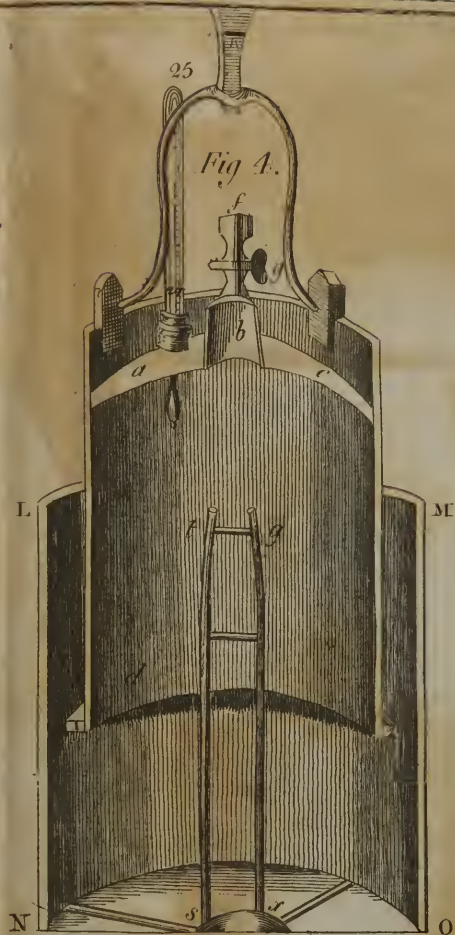
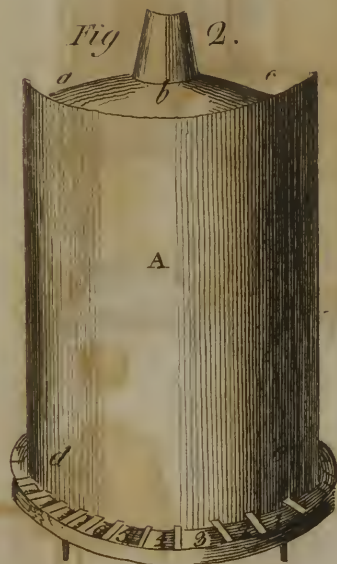
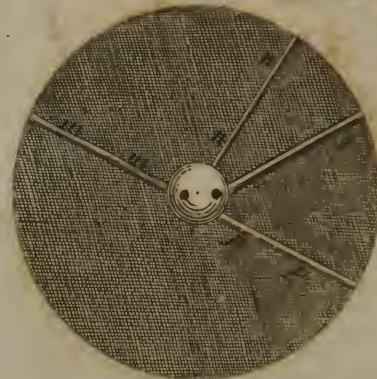


Fig 2.



Fig



3.



PLATE I.

Fig 5.



Scale of Feet

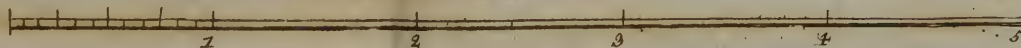






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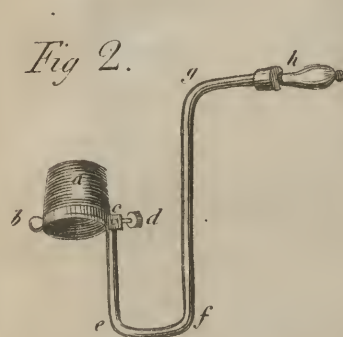
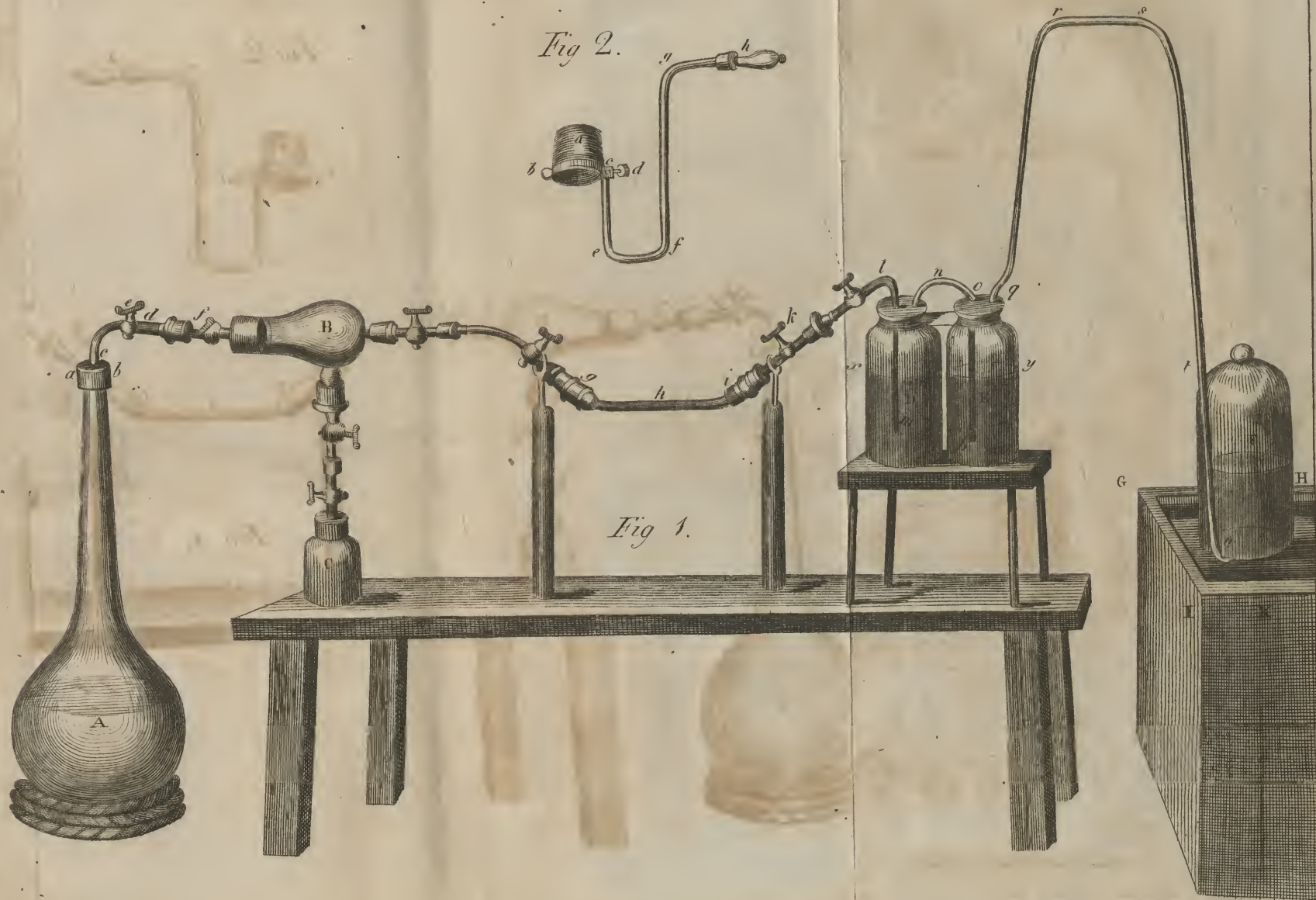
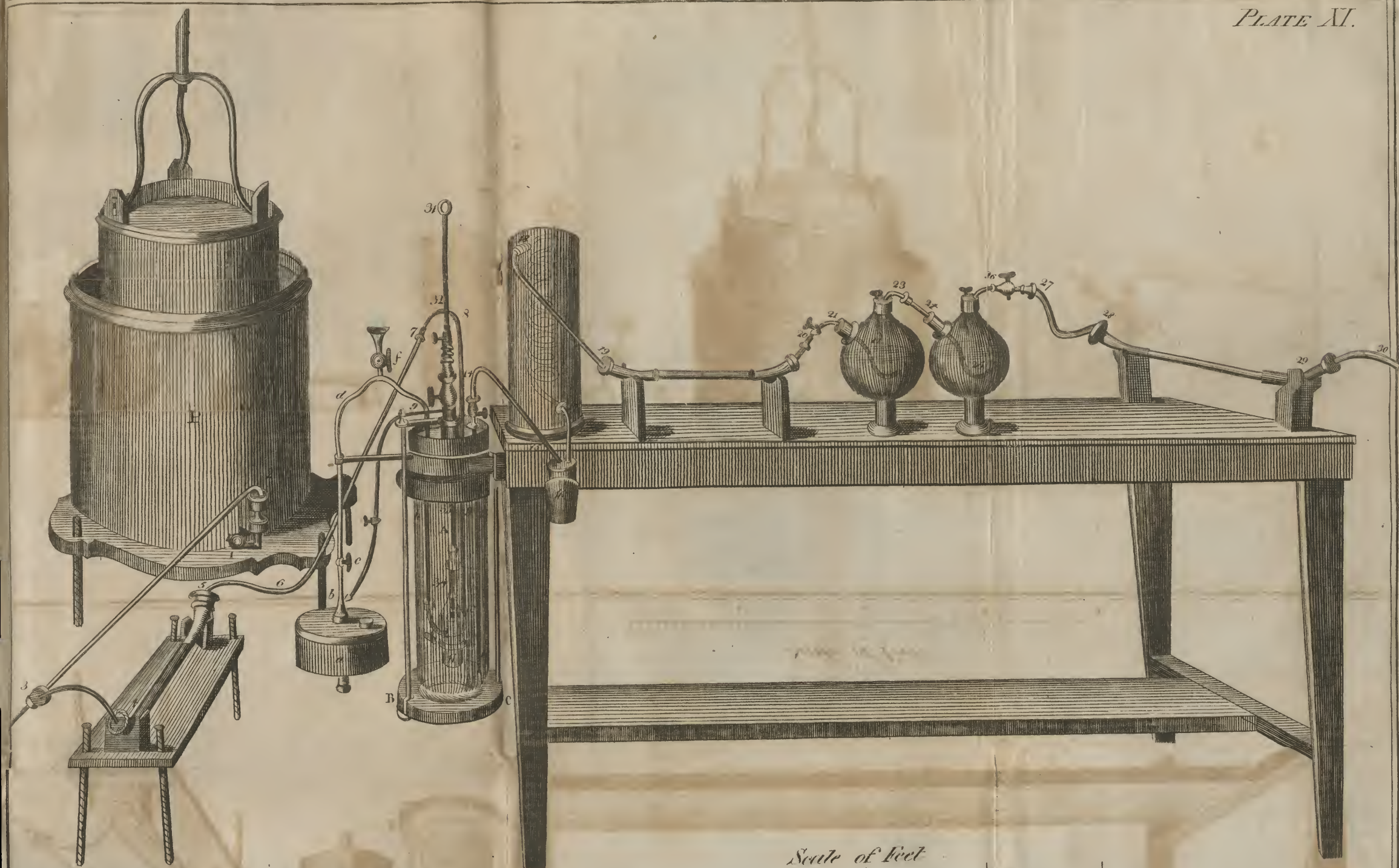


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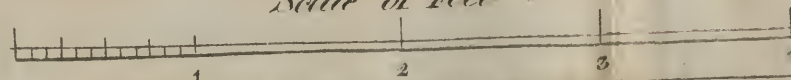






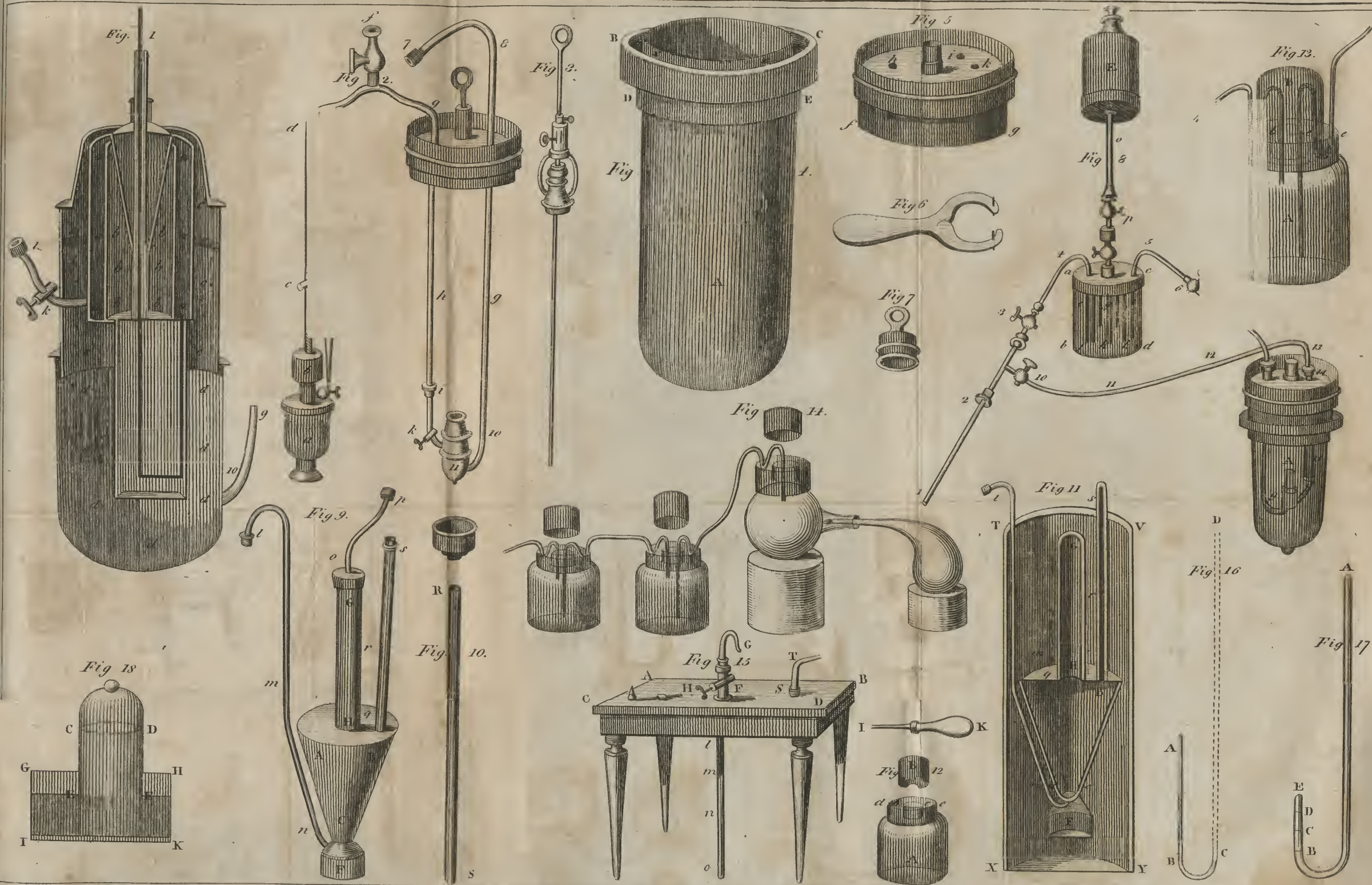


Scale of Feet











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Fig. 1.



Fig. 2.



Fig. 3.



Fig. 7.



Plate XIII.

Fig. 8.

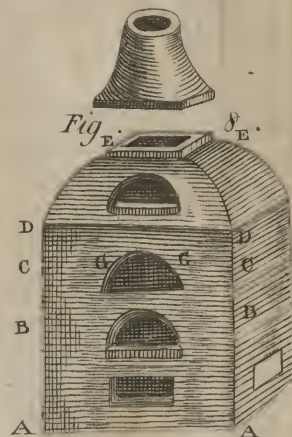


Fig. 9.



Fig. 10.

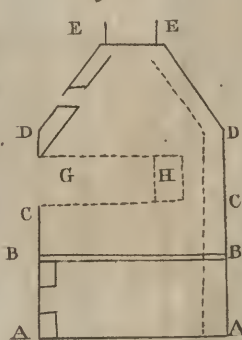


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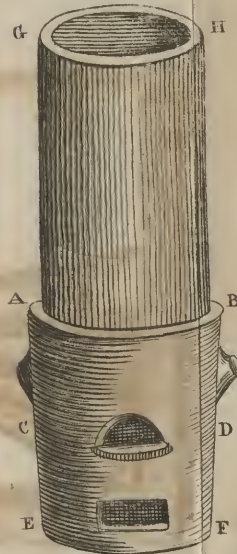
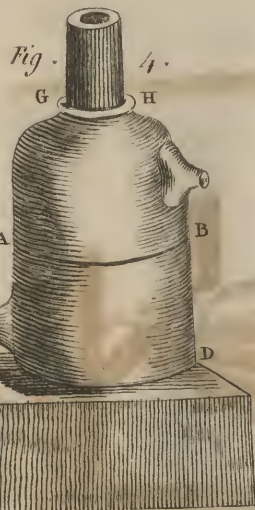
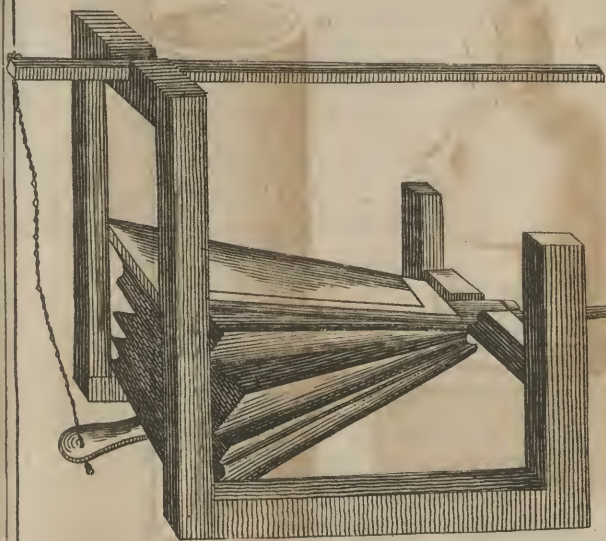
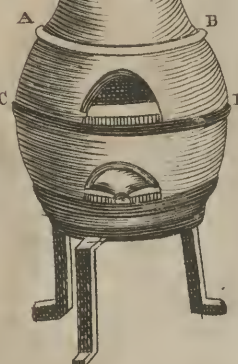


Fig. 6.











Elements of Chemistry, Fourth Edition.

Lavoisier

Philadelphia: 1799

National Library of Medicine

Bethesda, MD

CONDITION ON RECEIPT:

The full leather binding was worn, particularly at the corners, edges, and joints. The leather on the front board was cut. The back board was detached. The front internal hinge was broken. The text block consisted of printed text and plates, many of which were oversized and folded several times. The sewing was intact. Most of the pages were discolored, acidic, and brittle. Some pages were foxed. Some plates were dirty. Many of these were improperly creased and torn along the edges. The exterior leaves were marked with graphite pencil and stamp ink. A bookplate was adhered to the front pastedown.

TREATMENT PROVIDED:

The head, tail, and pages were dry cleaned. Tears were mended and folds guarded with Japanese kozo paper and wheat starch paste. Improperly creased areas of the plates were flattened. The binding was repaired by reattaching the back board using airplane linen, and the internal hinges were reinforced using Japanese kozo paper colored with acrylic pigment.

Northeast Document Conservation Center

February 2002

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